Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and the Hydrology-Based Environmental Flow Regime (HEFR) Methodology

Third Edition

Senate Bill 3 Science Advisory Committee for Environmental Flows

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SECTION 1
INTRODUCTION

Environmental flows, which include flows in rivers and streams and freshwater inflows to bays and estuaries, have not been addressed uniformly in water development project planning and permitting in Texas. Senate Bill 3 (SB 3), passed by the Texas Legislature in 2007, set out a new regulatory approach to protect such flows through the use of environmental flow standards developed through a local stakeholder process culminating in Texas Commission on Environmental Quality (TCEQ) rulemaking. SB 3 directed the use of an environmental flow regime in developing flow standards and defined an environmental flow regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats.

The nature of streamflow magnitudes and variations plays an important role in determining the characteristics and viability of a riverine ecosystem. In water bodies having a sound ecological environment, historical hydrology has likely been a dominant factor that has influenced the state of the system. Where data are insufficient to establish relationships between streamflow and biological response, the historical streamflow data themselves can provide a meaningful basis for establishing, as a first approximation, environmental flow recommendations that are considered to be protective of current conditions. It is also necessary that these initial recommendations be subject to refinement and adjustment based on available biological data and other information to better reflect actual ecosystem needs.

This document provides an overview of how hydrologic data may be used in the identification of instream flow recommendations pursuant to the requirements of SB 3. As such, it describes one piece of the collaborative process envisioned by SB 3 for the identification of flows to maintain a sound ecological environment in rivers and streams.[1] Other disciplines such as biology, geomorphology, and water quality, although not discussed directly in this report, also warrant specific attention to ensure that instream flow recommendations are based on the broadest set of information available.

It is important to recognize that the provisions of SB 3 dealing with environmental flows are structured specifically to provide a mechanism for protecting certain levels of flow for environmental purposes while at the same time allowing for the use of surface water to meet other needs, including human water needs. The discussion in this document pertains only to the scientific aspects of establishing appropriate environmental flow requirements for river and streams and does not consider the needs of other users or uses for which surface water flows may be required. In the context of the SB 3 process for developing environmental flow recommendations and standards, this document is directed primarily at the scientific work undertaken by the Bay and Basin Expert Science Teams (BBEST); however, it also has

[1] Freshwater inflow recommendations for bays and estuaries are not addressed in this document. They are discussed in another companion document.

application during deliberations of the Bay and Basin Area Stakeholders Committees (BBASC) and the TCEQ to establish recommended environmental flow standards.

Section 2 of this document provides background information on relevant legislation, flow regime concepts, and hydrologic data. Section 3 highlights resources and methods that can be used to generate instream flow recommendations using hydrologic data. Section 4 introduces decisions that must be made when using hydrologic data to define flow recommendations.[2] Section 5 describes the Hydrology-based Environmental Flow Regime (HEFR) method. Section 6 provides concluding remarks. Clarifying examples are provided throughout this document to provide context to the reader. Such examples are solely intended to illustrate the types of factors that could be considered and should not be construed as recommendations.

This document originally was prepared by the Texas Parks and Wildlife Department (TPWD) at the request of the SB 3 Science Advisory Committee (SAC), with comments from the Texas Water Development Board (TWDB) and TCEQ. Members of the SAC have reviewed, edited, and expanded the document and have provided recommendations regarding the application of the information and procedures presented in the document pursuant to the requirements of SB 3.

The first version of this document was officially released by the SAC on February 9, 2009 as report # SAC-2009-01. The first revision (Rev1) was officially released on April 20, 2009 as report # SAC-2009-01-Rev1. The present document represents the third edition and is report # SAC-2011-01, dated March 15, 2011.

[2] Section 4 is largely based on a previous document entitled "Decision Points Relevant to using Hydrology Data to Quantify Environmental Flow Recommendations" that was provided to the SAC in draft form in October, 2008.

SECTION 2
BACKGROUND

2.1 INTERSECTION OF SENATE BILLS 2 AND 3

In 2001, Senate Bill 2 (SB 2) created the Texas Instream Flow Program (TIFP) which mandated that TPWD, TWDB, and TCEQ conduct studies to determine appropriate methodologies for determining flow conditions in the State's rivers and streams necessary to support a sound ecological environment.[3] Priority studies of the lower Sabine, middle Trinity, middle and lower Brazos, lower Guadalupe, and lower San Antonio rivers are to be completed by December 31, 2016. The TIFP is intended to be transparent and to strive for compatibility with existing programs. The methodology provides a general framework for studies across the State but recognizes that individual studies must be tailored to address basin and stream conditions.

Senate Bill 3, passed in 2007, established an aggressive schedule for determining environmental flow standards adequate to support a sound ecological environment in the State's river basins and bay systems.[4] These standards must consist of a schedule of flow quantities, reflecting seasonal and yearly fluctuations that may vary by location.[5] The SB 3 schedule does not allow for the development of multi-year site-specific instream flow studies such as those mandated by SB 2. Instead, SB 3 requires that environmental flow standards be predicated upon the best science and data currently available; it is intended that adaptive management be employed to refine the flow standards in the future.[6] In order to effectively use the results from the TIFP studies through the adaptive management process, it is considered desirable for the initial SB 3 flow standards to be consistent with the environmental flow regime framework that is to be applied in the TIFP studies for structuring environmental flow recommendations.

The immediate task for developing the flow standards required under SB 3 is to identify in a short time frame and without the benefit of completed TIFP studies one or more scientifically-based methods for determining an environmental flow regime at a particular location on a stream that will support a sound ecological environment and maintain the productivity, extent, and persistence of key aquatic habitats. The extent to which such an environmental flow regime conforms to the basic structure of that being proposed for application in the TIFP studies is an important consideration. Incorporating the results of TIFP studies into SB 3 environmental flow regimes may be greatly facilitated if the initial environmental flow regime recommendations are consistent with the TIFP flow regime components.

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[3] Texas Water Code § 16.059 (Vernon 2008).
[4] Texas Water Code § 11.02362 (Vernon 2008).
[5] Texas Water Code § 11.1471(c) (Vernon 2008).
[6] *See* Texas Water Code §§ 11.02362(m) and (p) (Vernon 2008).

2.2 INSTREAM FLOW REGIME COMPONENTS

Variations in the magnitude, frequency, duration, timing, and rate of change of stream flows are all critical components of a natural flow regime (Poff et al., 1997). Variability in stream flow is manifested to stream biota as a change in habitat availability. Consequently, the life histories of stream fishes and other aquatic organisms are adapted to the seasonal and interannual variability of low, base, and high flow components. Hydrologic pattern and variability are therefore key determinants of aquatic community structure and stability (Poff and Ward, 1989; Poff et al., 1997; Richter et al., 1996, Dilts, et al., 2005).

Alterations to a natural flow regime may result in decreased richness, diversity, and abundance of aquatic species inhabiting lotic systems. While the elimination of high flows can result in reduced species densities and community diversity (Robinson et al., 1998), stable flow regimes that lack seasonal and interannual variability may favor generalist and non-native species (Tyus et al., 2000). In addition, seasonal and interannual flow variability may benefit native species that have developed life history strategies in response to natural flows. Thus, providing a flow regime based on the natural flow paradigm should provide ecological benefits in stream systems (Dilts et al., 2005; Richter, 2009).

To date, most instream flow recommendations in Texas have used a single "minimum" flow standard, which may vary by month and location (see discussion on Lyons Method below). Conversely, instream flow recommendations based on a flow regime concept (such as the regime concept found in SB 3) consist of multiple flow regime components (or levels) with specific characteristics. Following the recommendation of the National Research Council (NRC, 2005), and consistent with Maidment et al. (2005), the TIFP (2008) uses a framework that consists of a set of four components of a flow regime intended to support a sound ecological environment. These instream flow regime components are primarily defined by their ecological roles and functions, and they include the following:

- Subsistence flows,
- Base flows,
- High flow pulses, and
- Overbank flows.

Subsistence flows are low flows that occur during times of drought or under very dry conditions (TIFP 2008). The primary objectives of subsistence flows are to maintain water quality and prevent loss of aquatic organisms due to, for example, lethal high temperatures and low dissolved oxygen levels. Secondary objectives may include providing life cycle cues based on naturally occurring periods of low flow or providing refuge habitat to ensure a population is able to re-colonize the river system once more normal, base flow conditions return.

Base flows represent the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events (TIFP 2008). Base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers. Habitat quality and quantity are important for survival, growth, and reproduction of fish and other aquatic organisms (e.g., mussels and benthic macroinvertebrates, other vertebrates, and flora). Base flows can also support the maintenance of water quality conditions and can contribute to the alluvial groundwater that supports riparian habitats, which are important components of river ecosystems. The structure and function of riparian areas are dependent on flow regimes and these areas serve to connect surface and subsurface hydrology with adjacent uplands (NRC 2002). For riparian vegetation, if the water table drops below the stream level, older, more mature trees may survive, but younger trees might die and seedlings may not successfully take root. Even mature vegetation might not survive if the water table remains below the root zone for an extended period of time.

High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events (TIFP 2008). High flow pulses serve to maintain important physical habitat features and connectivity along a stream channel. Many physical features of a river or stream which provide important habitat during base flow conditions cannot be maintained without appropriate high flow pulses. High flow pulses also provide longitudinal connectivity along the river corridor for many species (e.g., migratory fish), lateral connectivity to near-channel features (e.g., connections to some oxbow lakes), and can support the maintenance of water quality.

Overbank flows are infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain (TIFP 2008). A primary objective of overbank flows is to maintain riparian areas associated with riverine systems. For example, overbank flows transport sediments and nutrients to riparian areas, recharge floodplain aquifers, and provide suitable conditions for seedlings. Overbank flows also provide lateral connectivity between the river channel and the active floodplain, supporting populations of fish or other biota utilizing floodplain habitat during and after flood events. Other objectives for overbank flows include the movement of organic debris to the main channel, providing life cycle cues for various species, and maintaining the balance of species in aquatic and riparian communities.

Additional (albeit not comprehensive) ecological roles for these different flow components based on Richter et al. (2006) and Richter and Thomas (2007) are summarized below:

<u>Subsistence Flows</u>

Sustain a minimum level of interconnection between pools
Provide sufficient flow to preclude lethal temperature and dissolved oxygen levels.
Purge invasive species

<u>Base Flows</u>

Provide habitat of sufficient depth and velocity, without excessive velocity which would require finding shelter
Maintain water tables levels for riparian vegetation
Enable fish to move longitudinally to feeding and spawning areas
Keep fish and amphibian eggs wet and suspended
Provide drinking water for terrestrial animals

<u>High Flow Pulses</u>

Provide migration and spawning cues for fish
Move fine sediments and expose cobbles and rocky substrate

Fill backwater areas and provide some lateral connectivity
Restore normal water quality conditions following prolonged dry periods.
Prevent riparian vegetation from growing in the channel
Scour macrophytes

Overbank Events
Provide migration and spawning cues for fish
Provide lateral connection with oxbows, riparian habitats, and floodplain areas
Shape physical habitats
Drive lateral movement of the river channel
Provide nursery areas for juvenile fish
Recharge the floodplain water table
Deliver sediments and nutrients to the floodplain and estuaries
Create key habitat features such as snags
Maintain diversity in floodplain forest

In addition to identifying individual flow regime components such as the four discussed above, it is important to adequately characterize the components themselves. Important aspects of these flow regime components, particularly the higher flow conditions, may include flow magnitude (rate and/or volume), duration, timing, frequency, and rate of change. Each of these characteristics may have important ecological implications and thus may need to be quantified (Poff et al., 1997; TIFP, 2008). For example, rise rates that are too rapid may wash aquatic organisms downstream before they can find shelter along the river margins. Conversely, fall rates that are too rapid may lead to stranding of aquatic organisms in shallow areas. However, from the standpoint of achieving environmental flow requirements associated with a water right on a stream or river, it is also important to recognize that fully satisfying the need for the episodic (i.e., high flow pulse and overbank) flow regime components often may be dictated more by the natural stream itself and local hydroclimatology than the water right activity. The diversions authorized by a water right or group of water rights may be of such magnitude that they simply cannot significantly impact high flow pulses or flows that cause overbanking.

2.3 HYDROLOGIC CONDITIONS VARY THROUGH TIME

Hydrologic conditions[7] vary through time (e.g., dry, average, and wet periods); recognition of this variability supports the development of commensurate instream flow recommendations. For example, base flow recommendations during wet conditions could be greater than base flow recommendations in dry conditions and fewer high flow pulses might be needed in average conditions than in wet conditions. It must be recognized that flow recommendations which take hydrologic conditions into account begin to reflect an attempt to balance the needs of both water users and the ecosystem.

[7] Hydrologic conditions could also be referred to as "climatic conditions," or "zones" in the parlance of the Texas Consensus Criteria for Environmental Flow Needs (CCEFN; TWDB, 1997), or "water year types" in the parlance of the Klamath River Instream Flow Recommendations (Hardy and Addley, 2001).

In the Caddo Lake/Big Cypress Creek Collaborative Process, different low flow (i.e., base flow) requirements were established for wet years, average years, and dry years.[8] A similar distinction was made in the Savannah River (Georgia) instream flow recommendations (NRC, 2005).

Varying hydrologic conditions can be considered in different ways in environmental flow regimes. One approach is to establish a set of triggers for defining different hydrologic conditions, such as wet, average, and dry, and then engage the appropriate environmental flow recommendations applicable to each hydrologic condition. As an example of this, the Sabine-Neches BBEST used upstream reservoir storage as an example of the trigger to define wet, average, and dry conditions and applied various base flows and high flow pulse tiers (as flow restrictions on future diversions) accordingly. A different approach was taken by the "flow regime" group of the Trinity-San Jacinto BBEST. This group recommended various base flow magnitudes and long-term attainment frequencies and did not explicitly address implementation of the various flow magnitudes during different hydrologic conditions. However, before the base flow requirements recommended by the Trinity-San Jacinto BBEST could be applied, it would be necessary to either use the provided attainment frequencies to establish appropriate triggers that would define the specific hydrologic conditions when the different base flow levels would be engaged or to provide some other method for determining when the different base flow levels would be engaged.

Hydrologic conditions can be associated with any period of time that appropriately defines hydrologic variations that may be considered important with regard to providing necessary levels of environmental flows, i.e., annually, semi-annually, seasonally, monthly, etc. (see Assignment Period discussion below).

The refinement of flow recommendations considering these varying hydrologic conditions may avoid imposition of unnecessarily stringent flow requirements, particularly if these conditions can be related to commensurate biological needs.

2.4 AVAILABILITY AND CONSISTENCY OF HYDROLOGIC DATA

Hydrologic data have several advantages for characterizing riverine systems over many other forms of environmental data in that they are relatively consistently and continuously measured at numerous locations and are also easily obtainable from the USGS.[9] These characteristics, along with the comparatively simple nature of the data themselves, mean that hydrologic datasets can be evaluated using fairly generic statistical approaches and tools. Thus, hydrologic data typically provide the most convenient, initial understanding of riverine systems.

While hydrologic data provide only one perspective, it can be an important one. In its review of the Texas Instream Flow Program, the National Research Council (NRC, 2005) stated that

[8] October 1, 2008 presentation to SB 3 SAC
[9] http://waterdata.usgs.gov/tx/nwis/current/?type=flow

"Hydrology is potentially the most critical element of instream flow studies and has been considered the "master variable" because the biology, physical processes, and water quality components directly relate to it (Poff et al., 1997)."

Furthermore, the NRC (2005) noted that

Hydrologic desktop methods can be very useful in obtaining a ballpark estimate of instream flow needs in rivers for which detailed instream flow studies have not yet been conducted.

In the context of SB 3, a reasonable approach might be to use hydrologic data to develop initial values for a flow regime and then modify selected values where additional information (e.g., water quality, biology, and geomorphology) is available. This is consistent with the approach taken on the Savannah River, as summarized in SAC (2004):

[The Savannah River program] include[s] the use of a desk-top method for establishing initial environmental flow values, an expert panel to review results and make decisions regarding what measures to implement, and adaptive management procedures to address scientific allowances for uncertainty… The environmental flow results from the desk-top analysis were treated as "place holders" for follow-on expert functional analysis of their site-specific ecological significance.

This approach is also consistent with current water permitting practices in Texas, as TCEQ frequently uses the hydrology-based Lyons Method (discussed below) for establishing environmental flow conditions for smaller water rights and more complex approaches for larger water rights.

SECTION 3
METHODS FOR USING HYDROLOGIC DATA TO DEVELOP INSTREAM FLOW RECOMMENDATIONS

3.1 AVAILABLE RESOURCES

There are several resources available for obtaining information on how to use hydrologic data for evaluating and establishing environmental instream flow recommendations. Two particularly relevant sources are briefly discussed here. Additional sources are provided as citations.

The Instream Flow Council has described and summarized a number of methods for assessing instream flow requirements (Annear et al., 2004). Over 30 techniques are grouped into three broad categories: Standard Setting, Incremental, and Monitoring/Diagnostic. Standard Setting methods (e.g., the Lyons Method) set limits to define threshold flow regimes and can be done relatively quickly using hydrologic data but are not considered as rigorous as methods that also use biologic data. Incremental methods (e.g., the SB 2 TIFP method) analyze one or more variables to enable assessment of different flow management alternatives. Incremental methods are often considered more scientifically accepted but also require more resources to execute since site-specific data must be collected. Monitoring/Diagnostic methods are those methods that can be used to assess conditions and how they change over time. An example of this type of method is the Nature Conservancy's Indicators of Hydrologic Alteration method (IHA).

Based on recommendations from the Science Advisory Committee created by the Study Commission on Water for Environmental Flows (Senate Bill 1639 from 2003), TCEQ created a Technical Review Group (TRG) to review available instream flow assessment tools and to develop one or more desktop methodologies specifically applicable to Texas river and stream conditions. The term "desktop" refers to methods that can be applied using readily available information and do not require site-specific field studies.

The TRG focused its initial review on desktop methodologies that have been applied to Texas streams (TRG, 2008). These included the Lyons Method, the Consensus Criteria for Environmental Flow Needs, the Texas Method and IHA. After further deliberation the TRG chose to focus its final review on the Lyons Method and IHA.

Key observations relevant to SB 3 include

> *"…the Lyons Method has some scientific basis for its construction, but the degree to which its monthly flow factors effectively represent varying stream conditions across the State remains unresolved."*

and

> *In the absence of any further information and primarily for the sake of continuity with past practices, we reluctantly recommend that the TCEQ continue to apply the Lyons Method as a desk-top approach for permitting purposes.*

Furthermore, the TRG recommended that

> *…the IHA Method may be utilized as a tool to provide guidance to TCEQ with regard to the different flow regimes that might be considered important for protecting instream environmental uses. Nonetheless this method appears impractical for use as the primary desk-top method for establishing environmental flow requirements for small-diversion permits or amendments.*

The TRG operated under the (fairly safe) assumption that any recommended desktop method would only be applied to small diversions that have little possibility of impacting high flow pulses and overbank flows. Thus, the lack of high flow pulse and overbank information in the Lyons Method was not identified as a significant weakness; indeed, high flow pulse and overbank flow recommendations could be seen as a superfluous complexity in small diversion permits. While SB 3 contemplates a multi-tiered flow regime that protects a sound ecological environment, there still may be situations where all aspects of that flow regime, particularly the high flow requirements, may not be appropriate for inclusion as environmental flow conditions on a new water right because the water right activity is of such magnitude that it cannot significantly impact such levels of flow.

Other summaries of instream flow methods, including hydrology-based methods, include Acreman et al. (2005), Maunder and Hindley (2005), Acreman and Dunbar (2004), Arthington and Zalucki (1998), and Jowett (1997).

Several specific methods are discussed below. Each of these specific methods could be used in the context of a larger collaborative effort such as SB 3.

3.2 ADVANTAGES AND DISADVANTAGES COMMON TO ALL HYDROLOGIC METHODS

Hydrologic methods share certain advantages and disadvantages (relative to biological, geomorphological, and water quality methods) in common. Common advantages include: (1) relatively robust and consistent datasets at multiple locations, (2) the understanding that hydrology has been considered the "master variable" with regard to environmental instream flows (Poff et al., 1997), and (3) ease of use.

Common disadvantages include: (1) a lack of validation against biological, geomorphological, and water quality data, because the methods are largely designed to mirror some fraction of a historical hydrologic record or a calculation of naturalized hydrology, and are not based on defined flow alteration - ecological response relationships, and (2) unsuitability where hydrologic data are lacking and cannot be reasonably synthesized.[10] Even though comprehensive datasets to define flow alteration – ecological responses are often unavailable, some biological, geomorphological, and water quality data will be available in each major river basin. Thus, following the application of any of these hydrologic methods, it is recommended

[10] Synthesizing hydrologic data involves a wealth of complexities that are beyond the scope of this document.

that this available data be used to corroborate or refine selected hydrology-based flow recommendations, as appropriate.

Important advantages and disadvantages specific to each individual hydrologic method are provided below in the discussion of each method.

3.3 LYONS METHOD

The Lyons Method (Bounds and Lyons, 1979) is a standard setting desktop methodology that uses monthly median gaged flow records to produce monthly instream flow recommendations with the intent of approximating natural flow patterns. The Lyons Method specifies 40% of the monthly median flow from October to February and 60% of the monthly median flow from March to September as minimum flows. The Lyons Method is statistically weighted to provide higher flows during the spring and summer periods, considered most critical to the warmwater fishes found in Texas. The flow values (i.e., 40% and 60% of median) used in the Lyons Method were based on the amount of wetted perimeter of the stream channel supported by limited physiographic field measurements in the Guadalupe River downstream of Canyon Dam.

TCEQ frequently uses a modified version of the Lyons Method as the basis for establishing environmental flow restrictions for new water right permits and amendments when existing site-specific information is not available. TCEQ typically imposes a lower flow limit equal to the 7Q2 if the Lyons derived value is less than the 7Q2. The 7Q2 is defined as the lowest average stream flow for seven consecutive days with a recurrence interval of two years, as statistically determined from historical data, and has been used by TCEQ and others as a minimum flow threshold for protecting water quality. In addition, TCEQ often groups or averages similar monthly values together to produce a reduced number of environmental flow recommendations within the year.

Advantages of the Lyons Method are that it is a simple, hydrology-based, desktop approach for determining minimum flow requirements for habitat protection and is used by TCEQ as the basis for setting restrictions in water right permits. A key disadvantage is that although the calculation generates a flow recommendation analogous to the base flow component, it cannot be used to estimate other flow regime components. There has even been some concern with regard to its potential use for the quantification of base flows. In their review of the Lyons Method, the NRC (2005) stated:

> *Use of monthly medians in a hydrologic desktop method can also yield inconsistent degrees of protection for base flows. Monthly medians are computed using all river flows during the month – base flows, high flow pulses, and even floods are all rolled into the calculation of a monthly median. As a result, it is often hard to predict how closely the median, or a method like Lyons, will compare to base flows.*

Another possible disadvantage is that the Lyons Method does not generate different flow recommendations for different hydrologic conditions (e.g., dry, average, wet), which, particularly for larger water rights, is important.

3.4 CONSENSUS CRITERIA FOR ENVIRONMENTAL FLOW NEEDS (CCEFN)

The CCEFN was developed in the mid 1990s using a stakeholder process led by the TWDB to address water supply demands while recognizing environmental flow needs (TWDB, 1997). The CCEFN uses percentages of naturalized daily flow and provides a tiered set of recommendations for passing flows through reservoirs and past diversion points to provide downstream environmental flows based on calculations of naturalized flow. The CCEFN was developed for use in the water planning process and is used in regional and state water planning and by the TWDB for water supply planning studies and occasionally has been applied by TCEQ in water rights permitting.

The CCEFN defines three zones for the determination of applicable environmental instream flow requirements, with the delineation of these zones being different depending on whether the resulting environmental flows are being applied to a direct diversion from a stream or a reservoir on the stream. For direct stream diversions, Zone 1 conditions occur when streamflow is greater than the naturalized median flow, and this value of flow must be passed downstream before any water can be diverted. Zone 2 occurs when streamflow conditions are greater than the 25th-percentile naturalized flow, but less than the naturalized median (and the 25th-percentile naturalized flow must be passed downstream before any water can be diverted). Zone 3 applies when streamflow decreases to less than or equal to the 25th-percentile naturalized flow and prescribes the minimum flow needed for water quality maintenance. For Zone 3, the minimum flow requirement is a fixed threshold such as the 7Q2 or another flow value. For an on-stream reservoir, zones are defined based on storage in the reservoir at any given time, with Zone 1 conditions occurring when the storage is greater than 80% of the full conservation storage capacity. Zone 2 conditions occur when the storage is between 50% and 80%, and Zone 3 occurs when the storage is less than 50% of the full conservation storage capacity. The requirements for passage of inflows through the reservoir to provide environmental flows downstream for each zone are the same as those defined above for direct diversions, e.g., when the reservoir is in Zone 1, the naturalized median flow must be passed downstream.

The CCEFN is a desktop methodology that relies on naturalized flows to produce an environmental flow schedule for planning purposes.[11] While the CCEFN does generate different flow recommendations under different hydrologic conditions ("zones"), it does not generate high flow regime components; the flow restrictions are all analogous to either subsistence or base flows. It is also questionable as to whether naturalized flows should always be used as the basis for establishing the different flow quantities. There are situations where historical flows may be more appropriate.

3.5 ECOLOGICAL LIMITS OF HYDROLOGIC ALTERATION (ELOHA)

The Ecological Limits of Hydrologic Alteration (ELOHA) uses existing hydrologic and ecological databases from many rivers within a region to generate flow alteration-ecological

[11] Note that while the CCEFN method was developed for daily flow values, its implementation in water planning necessarily uses the State's Water Availability Models (WAMs) that operate on a monthly time step.

response relationships and environmental flow targets. ELOHA envisions multi-step scientific and social processes that involve scientists and stakeholders:

Scientific Process:
Step 1: Build a hydrologic foundation
Step 2: Classify river segments
Step 3: Compute hydrologic alteration
Step 4: Develop flow alteration-ecological response relationships

Social Process:
Step 1: Determine acceptable ecological conditions
Step 2: Develop environmental flow targets
Step 3: Implement environmental flow management

Advantages of ELOHA include (1) a similarity to the SB 3 framework (e.g., scientific and social elements), (2) the use of existing data (e.g., daily gaged flows) and tools (e.g., TX-HAT to classify river segments and IHA to compute hydrologic alterations and develop environmental flow targets) to do a majority of the steps, and (3) application at a regional or basinwide scale.

A key disadvantage of ELOHA is that while some information for completing step 4 of the scientific process may exist, it is likely that sufficient information to effectively define flow alteration – ecological response relationships currently only exists on the lower Colorado River, and such information is not likely to be available on other rivers until more studies, such as the SB 2 TIFP, are complete. To date, ELOHA has not been implemented in Texas and no specific guidelines for how ELOHA can be used are available, thus it is uncertain how long this process would take.

More information on ELOHA may be found at www.Nature.org/ELOHA.

3.6 INDICATORS OF HYDROLOGIC ALTERATION (IHA)

The Nature Conservancy's Indicators of Hydrologic Alteration (IHA) is a software package that is used to assess streamflow conditions and how they change over time. The package was developed to provide hydrologic analysis in an ecologically-meaningful manner. The software program assesses 67 ecologically-relevant (in the opinion of the IHA authors) statistics derived from daily hydrologic data. IHA requires an input file of daily streamflow data which typically can be obtained from the USGS. To adequately capture annual and inter-annual variations in the flow record, 20 or more years of continuous daily flow data are recommended (Richter et al., 1997). The USGS currently lists 498 active Texas gages on their website;[12] additional flow data may be available at selected locations from river authorities and other entities.

IHA also has a feature called the Environmental Flow Components (EFC) model in which each day is assigned one (and only one) of five flow regime categories: extreme low flow, low flow,

[12] http://waterdata.usgs.gov/tx/nwis/current/?type=flow

high flow pulses, small floods, and large floods; an algorithm parses the hydrograph accordingly based on user defined parameters and then generates summary statistics corresponding to each flow regime component.

To date the IHA method has not been fully implemented for any projects in Texas, although there have been applications elsewhere, often in conjunction with another method such as the Range of Variability Approach (RVA). In Texas, the EFC algorithm of IHA has been used in development of the Hydrology-based Environmental Flow Regime (HEFR) method (see discussion below) and in the Caddo Lake/Big Cypress Creek Collaborative Process. IHA software is readily available and relatively easy to use. Although the technique does not directly provide an environmental instream flow prescription, it can be used to support instream flow studies. It can also be useful in determining the characteristics of the natural hydrograph that have been most altered (Annear et al., 2006). While IHA statistics reflect conditions associated with intra-annual variations in hydrologic regimes, ecosystem processes that operate at longer time scales may not be adequately addressed (Annear et al., 2006).

More information on IHA may be found at www.Nature.org/IHA.

3.7 TEXAS HYDROLOGIC ASSESSMENT TOOL (TX-HAT)

The USGS Hydroecological Integrity Assessment Process (HIP) is a suite of software tools that can be used for stream classification, addressing instream flow needs, and assessing hydrologic alterations. A key computational foundation for HIP is a software package called the Hydrologic Assessment Tool (HAT). HAT was recently customized for Texas under a contract between the USGS and TCEQ and is known as TX-HAT (USGS, 2007). HAT and TX-HAT have identical statistical computations and are essentially synonymous for purposes of this discussion.

HAT has many of the same statistical features as IHA. Relative to IHA, it has an expanded list of statistics, but does not parse the hydrograph into flow regime components. A recent comparative review of IHA and HAT was performed by Hersh and Maidment (2006).

HAT/TX-HAT has not been applied in Texas for the purpose of developing environmental instream flow requirements and the stream classifications have not been thoroughly vetted.

More information on HIP/HAT may be found at
www.fort.usgs.gov/Resources/Research_Briefs/HIP.asp.

3.8 HYDROLOGY-BASED ENVIRONMENTAL FLOW REGIME (HEFR)

The Hydrology-based Environmental Flow Regime (HEFR) method is a new, relatively flexible statistical approach for developing a flow regime matrix that is consistent with the Texas Instream Flow Program in the sense that it identifies multiple flow regime components of various levels across different months, seasons, or years. The development of HEFR was initiated by TPWD with input from other agencies and organizations as an alternative to the Lyons Method for use in water rights permitting. Although the method as a whole has not been peer reviewed, the Environmental Flow Components (EFC) algorithm and IHA software have been used extensively. In addition, HEFR forms the framework for the environmental flow recommendations in the Brazos River Authority's Systems Operation draft water rights permit pending at the TCEQ. To date, HEFR has been used by all of the BBESTs in their deliberations and development of flow regime recommendations.

HEFR is a work in progress; the most recent enhancements were completed in January 2011 and are documented herein.

The method is based on simple summary statistics of individual flow regime components. Generally, either the EFC algorithm (in the IHA software) or the Modified Base Flow Index with Threshold (MBFIT) method (implemented in a Microsoft Excel™ spreadsheet and discussed in Section 5) is used as a convenient tool to parse a hydrograph into individual flow regime components. Excel is then used to efficiently develop summary statistics of these flow regime components. Other software tools could be used for either or both of these steps.

In the context of SB 3, the HEFR methodology has several advantages, including: (1) it is computationally efficient, allowing for repeated tests and exploratory analyses, (2) there is significant flexibility in setting parameters to parse the hydrograph as well as summary statistics of the flow regime components,[13] (3) the results have the same format as expected results from the TIFP studies, and (4) it provides an initial set of recommendations that reflect key aspects of the natural flow regime including multiple flow components and hydrologic conditions (Poff et al., 1997). Disadvantages of this method are: (1) that there is no track record of application beyond SB 3 efforts, (2) there are few precedents for some of the decisions that must be made by the analyst, and (3) raw HEFR outputs may be overly complex and may need to be simplified for certain locations and contexts.

[13] Two examples where this might be helpful include: (1) different options could be selected for stream segments corresponding to Exceptional, High, Intermediate, and Limited Aquatic Life Use subcategories, and (2) different options could be selected for small versus large watercourses, based on evidence that small streams require a larger proportion of average flow than large streams for an equal amount of protection (Jowett, 1997).

SECTION 4
DECISION POINTS WHEN USING HYDROLOGIC METHODS

This section introduces common decision points encountered when using hydrologic data to help define environmental flow recommendations.

The decision points herein are considered to be applicable to any hydrology-based instream flow method. Specific methods will generally require additional decisions related to the exact computations used.

Many of the decision points described herein have been discussed and addressed in other contexts, such as TRG (2008), the ongoing work being performed in support of the LCRA-SAWS Water Project,[14] and applications of the Indicators of Hydrologic Alteration method (IHA) throughout the country.

In this section, the word "analyst" is used to generically refer to an appropriate decision maker(s). In the real world, this may include the Environmental Flows Advisory Group (EFAG), SAC, BBESTs, BBASCs, the TCEQ, or other persons or entities.

1. Number of Instream Flow Regime Components

The analyst must decide how many flow regime components to use and what aspects of the hydrograph they should represent. As discussed above, the TIFP uses four flow regime components (subsistence flows, base flows, high flow pulses, overbank flows[15]). IHA has five flow regime components (extreme low flows, low flows, high flow pulses, small floods, large floods), but can easily be constrained to fewer components.

All selected flow regime components must subsequently be defined. Both NRC (2005) and TIFP (2008) include definitions that may be suitable (see also Section 2.2). Once results from the hydrologic analysis are available, it may be appropriate to revise either the number of flow regime components or the definitions of the components to better reflect site-specific circumstances and conditions.

2. Geographic Scope of all Instream Flow Recommendations and Spatial Extent of Individual Instream Flow Recommendations

The analyst must identify the geographic scope of watercourses that will be assigned flow recommendations, as well as the spatial extent of each individual instream flow recommendation if such recommendations are applied to river reaches instead of point locations. Examples of information that may guide these decisions include: (1) the study reaches specified in the TIFP, (2) appropriately selected control points defining key hydrologic features such as major stream segments or downstream of an existing reservoir, (3) bodies of "state" water in the watershed of interest, (4) TCEQ classified water quality segments (note that many classified segments exist

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[14] www.lcra.org/lswp/index.html

[15] The high flow pulse and overbank flow recommendations may include a range of flow magnitudes and characteristics.

within the pools of major reservoirs), and/or (5) streams included in a particular GIS coverage (e.g., the NHDinGEO Dataset, http://nhd.usgs.gov/index.html). A flow recommendation quantified at a USGS gage location may apply upstream to the next USGS gage, downstream to the next USGS gage, both, or otherwise. One complicating factor that can arise when applying a hydrology-based flow recommendation (computed at a gage) to other locations is accounting for the influence of inflows from intervening drainage areas and tributaries.

The SAC, with support from the State agencies, also has prepared a separate document dealing with the geographic scope and spatial extent of instream flow recommendations. This document provides more in-depth information regarding the important factors that must be considered when establishing the locations within a basin where environmental instream flow recommendations are to be established (SAC, 2009a).

3. Hydrologic Period of Record

In any hydrology-based method, the analyst must decide whether or not to use the entire data record, and, if not, the analyst must decide which period to use. While this decision can take many forms, the three most common are (1) natural (the closest to pre-human impact achievable), (2) post-human impact or regulated (beginning with identifiable changes in hydrology), or (3) the entire period of record. One perspective holds that the natural period of record provides information on the flow conditions under which the ecosystem (including biological and geomorphological components) at the location of interest has evolved (BIO-WEST, 2008). This perspective is purported to facilitate protection of a sound ecological environment as well as the potential restoration of the natural system or portions of the natural flow record that could be restored, as opposed to attempting to protect some modified version of the natural system, with the full knowledge that complete reconstruction of the natural system may not be realistic. As an example of this perspective, the TRG (2008) concluded that "whenever feasible, historical pre-impact flow records should provide the basis for evaluating environmental flow targets." The key here is the word "feasible", suggesting that the state of the existing or recent hydrologic/ecologic system being considered may play an important role in determining which hydrologic record should (or could) be used for establishing environmental flow recommendations. As another example, the second recommendation in the NRC (2005) Executive Summary states that "state-of-the-science programs use natural flow characteristics as a reference for determining flow needs." Conversely, depending on the extent of human impacts, certain aspects of the lotic ecosystem may have adapted to the more recent flow regime and some components of a natural flow regime may no longer be appropriate (e.g., large overbanking events in highly developed floodplains or downstream of a major reservoir). For locations with little to no human impact, it is generally recommended that the entire flow record be used in order to work with the most robust dataset possible. TCEQ frequently uses the entire flow record when applying the Lyons Method. The CCEFN method uses naturalized flows, which are gaged flows adjusted to remove the effects of diversions and impoundments. These decisions regarding the hydrologic period of record should appropriately be made on a site-specific and case-specific basis.

A related issue is where to "break" the flow record if pre- or post-human impact is desired to be reflected in the environmental flow recommendations. Statistical tools, such as IHA and TX-HAT, have specific capabilities to help identify statistically different periods, although professional judgment and historical knowledge are also required. The analyst may also encounter breaks in a flow record that require concomitant decisions, such as choosing a period of record without a flow break or filling in breaks using a nearby gage with an acceptable flow correlation. In addition, depending on project objectives, the analyst may have a specific reason to include, or exclude, the 1950s drought of record in their analysis; although, for conducting water availability evaluations for a proposed water use, the drought of record (which often is the 1950s drought) is always included to provide a meaningful representation of the anticipated variations in the available water supply. Finally, the analyst must decide if the desired period of record is long enough to support a hydrologic analysis and is representative of hydrologic variability at the site (this decision must be made on a site-specific basis; however, as generic guidelines, the IHA manual recommends at least twenty years and the TRG (2008) recommends 30 years; see also Huh et al. (2005) and Kennard et al. (2010)).

The hydrologic period of record decision point includes many complexities and this discussion is not comprehensive. The goal of this section is simply to introduce the subject and provide examples of this decision made by other groups.

4. Different Base Flow Levels and/or High Flow Pulse Tiers

The analyst may wish to define various levels of base flows and/or high flow pulses, which may be applicable during different hydrologic conditions (e.g., wet, average, or dry), may be associated with different long-term attainment frequencies, or may be subject to other implementation methodologies. The SAC discussion paper "Consideration of Attainment Frequencies and Hydrologic Conditions In Developing and Implementing Instream Environmental Flow Regimes", dated January 1, 2011, addresses attainment frequencies and how they might be considered in implementing different levels of environmental flow requirements as part of an overall flow regime.

5. Assignment Period (Seasonality)

Flow regime components that consist of continuous flow recommendations may vary by time period (e.g., monthly or seasonal). Thus, the analyst must decide appropriate time periods for which to assign different values for these recommended flows. Complex episodic flow regime components such as high flow pulses and overbank flows occur intermittently and thus must be associated with a recommended frequency of occurrence over the desired assignment period. The assignment periods need not be identical for all flow regime components. However, for all flow regime components where seasons are desired, the length and monthly assignments to such seasons must be decided.

6. Interpretation of Long-Term Statistics

Hydrologic statistics are generally construed to be descriptive of long-term behavior. Depending on the statistical methods used, some interpretation of the results may need to be provided by the analyst. For example, does the high flow pulse recommendation for a particular season change if preceding seasons exceeded their recommendations versus if preceding seasons did not? This topic is highly dependent on other interpretation and implementation decisions made by the analyst, and it may be overly complex for consideration in real world applications of environmental flow requirements.

7. Flow Regime Component Characteristics Delineated

High flow pulses and overbank flows may be delineated using: (1) peak flow, (2) average flow, (3) duration, (4) volume, (5) rise and/or fall rate, (6) frequency, and/or other characteristics. The analyst must decide which of these (or other) characteristics are important to include in the environmental flow recommendations. Deviations between the characteristics used to computationally define these flow regime components and the characteristics explicitly included in final environmental flow recommendations may result in unintended consequences. For example, if high flow pulses are quantified in the historical record using a combination of average flow and duration, but recommendations simply specify average flow, high flow pulses of insufficient duration may result. Still, it is also important to recognize that the use of complicated multi-parameter definitions for high flow pulses and overbank events can be particularly challenging when implementing these types of environmental flow requirements in real situations.

8. Subsistence Flows and Water Quality

Some analytical methods may generate subsistence flows (or even base flows) that are less than flows associated with critical water quality functions and/or regulatory requirements. For example, this can easily happen if the 7Q2 is determined from current flows and the analysis is based on flows from a different time period. The analyst must decide if/when it is appropriate to recommend flows where some water quality standards would not apply. In the modified Lyons approach frequently used by TCEQ, the 7Q2 flow is considered a minimum: "Where the 7Q2 value is greater than the Lyons numbers, 7Q2 is used" (Loft, 2008). On the other hand, it is worth noting that the provision for water quality standards not applying at flows below the 7Q2 is a legacy of days when there were higher waste loads and dilution was important in standards attainment and waste load allocation modeling. With today's level of wastewater treatment, dilution is much less of an issue for parameters like dissolved oxygen. Standards are often met at flows less than 7Q2.

9. Number and Location of Control Points

The analyst must determine the requisite number and locations of control points at which to perform the hydrologic analyses. The previous discussion of the spatial extent of instream flow recommendations (item 2 above) and information contained in the document titled "Geographic Scope of Instream Flow Recommendations" prepared by the SAC and the State agencies provide additional guidance regarding the number and location of control points. However, the application of hydrologic methods, by their very nature, requires that the stream locations considered essentially be at streamflow gaging sites unless credible streamflow data can be synthesized. It is important that a sufficient number of sites be used in the hydrologic analysis for establishing environmental flow requirements to ensure adequate coverage with respect to streamflow characteristics (mainstem segments versus tributary reaches), existing and proposed water supply development projects (reservoirs, major water users), and ecological variations within a basin.

A list of active USGS flow gages in Texas is available at
http://waterdata.usgs.gov/tx/nwis/current/?type=flow.

10. Flow Recommendations in the Absence of a Flow Gage

There may be locations where instream flow recommendations are required or desired but a flow gage does not exist (e.g., tributaries that do not have a flow gage). In these cases, one option would be to translate the flow record at a nearby gage to the location of interest, e.g., using drainage area ratios (see, e.g., Asquith et al., 2006) and then perform the hydrologic analysis as usual. Another option would be to extrapolate a flow recommendation itself from a nearby location. Extrapolation of the flow recommendation is less desirable because it is likely subject to greater uncertainty than extrapolation of flow records. In either case, the analyst must determine that such translations are hydrologically realistic and meaningful; for many tributary/mainstem combinations, this may not be possible. The translation of either flow data or flow recommendations may be improved by limiting such translations to within a single stream classification. Information on stream classifications can be obtained from Hersh and Maidment (2007), Arthington et al. (2006), and Snelder et al. (2005).

11. Daily Average versus Instantaneous Flow Data

Daily average flow data are readily available[16] and are generally satisfactory for subsistence flow and base flow determinations. Daily average data also may be satisfactory for developing high flow pulses and overbank flow recommendations, or a method using instantaneous flow data may be desired. Instantaneous flow data from the USGS are not as thoroughly quality controlled as daily average flow data, are not available at all stations, and typically start in the late 1980s.[17] For these reasons, a pre-human impact flow record is unlikely to be available and a flow record in excess of 20 years is also unlikely. Typically, the more rare an event is (e.g., a large flood), the more important it is to use instantaneous data and the longer the period of record necessary to accurately quantify the expected frequency of the event. Previously developed flood models may be helpful to quantify flood events where data records are of insufficient duration.

While the use of daily average flow data is clearly unacceptable for the strict quantification of extreme flood events in the context of engineering and flooding impact determinations, the analyst may decide that, with some professional judgment, the use of daily average flow data is acceptable for setting realistic high flow pulse and overbank environmental flow recommendations.

12. Overbank Recommendations

Overbank flows are infrequent, high flow events that exceed channel banks and result in the inundation of the adjacent floodplain habitats. This periodic connection between the stream and the floodplain is critical for maintaining ecosystem health. It is important that overbank flows be recognized, to the extent practicable, in establishing instream flow recommendations to support a sound ecological environment in rivers and streams. However, overbank flow recommendations may raise issues of liability and should be carefully scrutinized by stakeholders and regulators as they address implementation of these flow recommendations.

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[16] http://waterdata.usgs.gov/tx/nwis/current/?type=flow

[17] http://ida.water.usgs.gov/

SECTION 5
HYDROLOGY-BASED ENVIRONMENTAL FLOW REGIME (HEFR) METHODOLOGY

5.1 HEFR BASICS

HEFR performs prescribed statistical analyses of a hydrologic dataset consisting of daily flows, and it was developed specifically to efficiently use hydrologic data to populate an environmental flow regime matrix. As a hydrologic method, it suffers from many of the same weaknesses as other hydrologic methods (see Section 3.2). However, unlike other hydrologic methods, HEFR can generate values for an entire flow regime in which the different flow regime components and component characteristics are internally consistent. The results are internally consistent in the sense that: (1) flow levels (e.g., low, medium, and high) are tied to percentiles of a distribution, and thus the magnitude recommendations by definition are ordered low < medium < high, (2) the hydrographic separation that generates the flow regime component values is performed using a single software tool (different tools are provided, but any given simulation will use only one), and (3) high flow pulse and overbank flow characteristics of duration, magnitude, and volume are generated using a consistent set of quantified flow regime components, as opposed to different statistical measures of the entire hydrograph (e.g., as in TX-HAT).

Similar to other hydrologic methods for developing environmental flow recommendations, HEFR identifies certain desired characteristics of the historical flow regime and builds a set of flow recommendations based on those characteristics. The expectation is that flows in excess of these specified characteristics are not part of the environmental flow recommendation and would be available for other uses (diversion and/or impoundment). Thus, while HEFR uses a user-specified portion of the historical period of record to generate flow recommendations, the recommendations do not mimic all historical flows, but rather (in any given season) a few selected components.

The HEFR process begins with the selection of a flow gage and a period of record. A hydrographic separation algorithm is then used to parse the daily hydrograph into the four flow regime components, based on user-specified parameters. This parsing results in each day of the hydrograph being classified as one of the four flow regime components. HEFR, which is an add-in for Microsoft Excel, then distills the daily flows and hydrographic separation results into a suite of summary statistics that may form the basis for an environmental flow recommendation. Figure 1 outlines the important steps of HEFR.

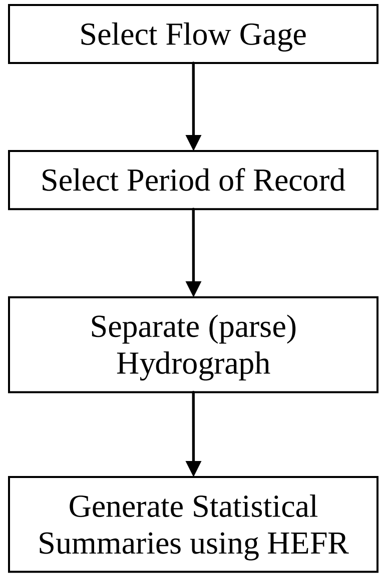

Figure 1. Flow Chart of HEFR Methodology

Thus, the core foundation of HEFR is flow separation and statistical summaries of each flow regime component. The specific decisions and tools used in the current version of HEFR were identified through discussions and negotiations; however, they are not incontrovertible. Decisions and tools may change because of location, professional judgment, context, objectives, and/or convenience.

For circumstances where the analyst wishes to efficiently execute multiple HEFR runs, IHA7.0 has a batch mode option (note that this option is not operational in v7.1), and HEFR 2.02 (and later versions) also can be run in batch mode by analysts comfortable with Visual Basic for Applications (VBA) code.

In the following sections, an example application of HEFR is presented as a convenient forum for describing the fundamentals of the method. Guidance is provided for each decision point. In this example, it is important to remember that the thought processes and guidelines are more important than the specific decisions and parameter values themselves. Application to other locations, other contexts, and the identification of site-specific data may all lead to different decisions. This example was developed for illustrative purposes only and has not benefited from the level of background research, collaboration, and site-specific knowledge that would be appropriate for a real-world application of the method.

The example described herein is for the Nueces River below Uvalde. In report SAC-2009-01 Rev1 (SAC, 2009c) an example is provided for the Neches River at Evadale.

5.2 EXAMPLE APPLICATION OF HEFR: NUECES RIVER BELOW UVALDE

5.2.1 Gage Selection

The Nueces River below Uvalde (USGS gage #08192000) was selected for this example because it has a long period of record (April 1939 to October 2010 as of this writing), has a low, but non-zero, frequency of zero flow days, and is not known to be in the vicinity of any significant current or future permit actions. This example application has been prepared solely for the purpose of presenting the HEFR methodology. The Nueces BBEST and BBASC are under no obligation to conform with any of the decisions described herein, nor should the decisions described herein, or the HEFR outputs, be considered in any planning or permitting context.

As shown in Figure 2, this gage is located on FM481 approximately 8 miles southwest of Uvalde in the western Hill Country region of Texas. The watershed area contributing to this location is 1,861 square miles. There are no major reservoirs upstream of this location.

Figure 2. Site Map for USGS Gage #08192000

The following sections are based on the flow chart shown in Figure 3. This figure highlights the primary decision points needed to run HEFR for this example. Decisions made for the Uvalde example are highlighted in blue. Options shown in white squares with rounded corners (e.g., MBFIT) lead to additional decisions that are not shown in this figure, because these options were not selected for this example. Thus, the figure does not show all possible HEFR decision points. This figure does include some of the key areas where additional information from other scientific disciplines should be used to guide HEFR decisions in real-world applications.

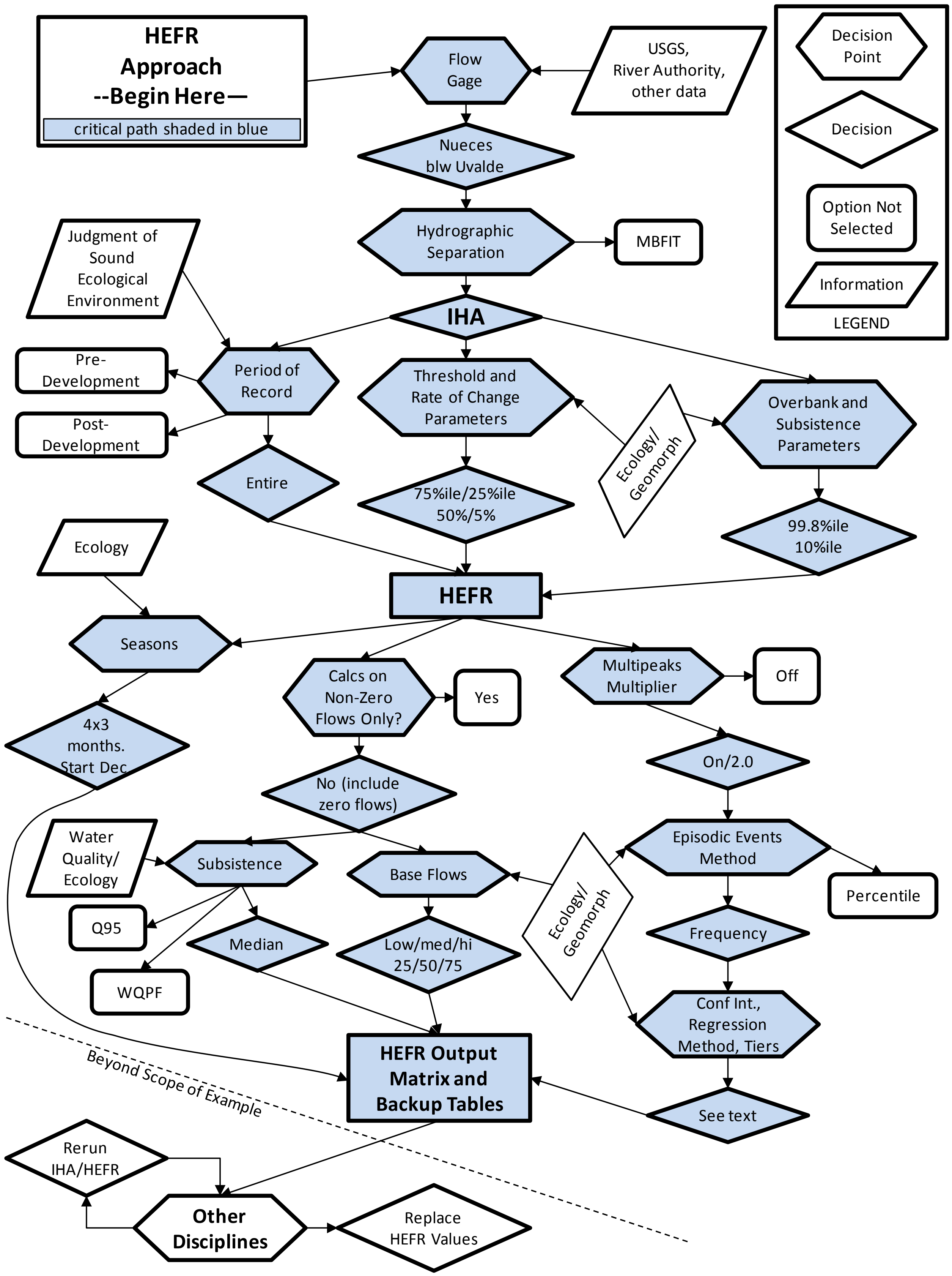

Figure 3. HEFR Decision Flow Chart for Uvalde Example

5.2.2 Period of Record

For the purposes of this example, the entire period of record was used. For a specific application, the analyst should consider several issues including: (1) are there major reservoirs, diversions, return flows, land use changes, and/or groundwater pumping changes upstream of the location in certain time periods that may influence the results, (2) is any part of the recorded history considered to not be reflective of a sound ecological environment, (3) should the period of record be selected to be as consistent as possible with the periods of record of nearby analysis locations, and (4) has the hydroclimatology changed over the recorded period of record and is that change expected to be permanent (e.g., climate change) or simply a reflection of long term climate variability.

To eliminate unnecessary complexities in the statistical interpretations, only full years of data are used; partial years are omitted. Also, calendar years (instead of USGS water years) are used. Based on these considerations, the period of record was selected to begin on January 1, 1940 and end on December 31, 2009. This results in 70 years of data, which meets the guidelines of the IHA software (in which 20 years or more are recommended) and the guidelines of the TRG (2008; which recommended 30 years).

5.2.3 Using IHA to Parse the Hydrograph

HEFR can employ the hydrographic separation outputs from two algorithms, IHA and MBFIT. For this example, IHA was selected.

The Nueces River below Uvalde site is primarily characterized by extended periods of low flow, which will easily be classified as subsistence or base flows (depending on the magnitude), and intense runoff events with significantly higher flow magnitudes, which will largely be classified as high flow pulses and overbank events. The more complex decisions include: (1) should small runoff events be classified as high flow pulses or base flows, and (2) should extended periods of higher flows (even if relatively steady) be classified as high flow pulses or base flows. The first of these (small runoff events) is relatively minor, as these constitute a small fraction of the period of record. The second issue is somewhat more significant and will be discussed further below. In the absence of site-specific knowledge, the major biological assumption taken in this example application is that the primary instream habitats and associated fauna at this location are exposed to persistent fairly low flows and therefore flows significantly in excess of these base flows should be classified as high flow pulses, even if occurring for an extended period.[18] In a 'real-world' application, these decisions and assumptions should be carefully considered by participants from various scientific disciplines.

[18] Accordingly, a high flow pulse event may persist for many months during a consistently wet year. This may differ from traditional base flow separation algorithms, which would typically assign steady flows to the base flow component, even if occurring at a high magnitude.

In order to perform the analysis, the number of flow regime components must be selected. Though the TIFP and IHA both incorporate the flow regime component concept, the terminology is not shared and there are subtle differences. For this example, the four flow regime components used in the TIFP are selected. These correspond to subsistence flows (i.e., extreme low flow in IHA), base flows (low flows), high flow pulses (same), and overbank flows (small and large floods). For consistency, the TIFP terminology is used throughout the text in this document, even though screen captures of the IHA tool show the IHA terminology. (see Section 3.6 for IHA flow component definitions).

The next decision to be made is the parameterization of the EFC algorithm in IHA. Figure 4 is a screen capture of this tool, with the selections used in this example (note that the large flood box is unchecked, effectively removing the large flood component from consideration).

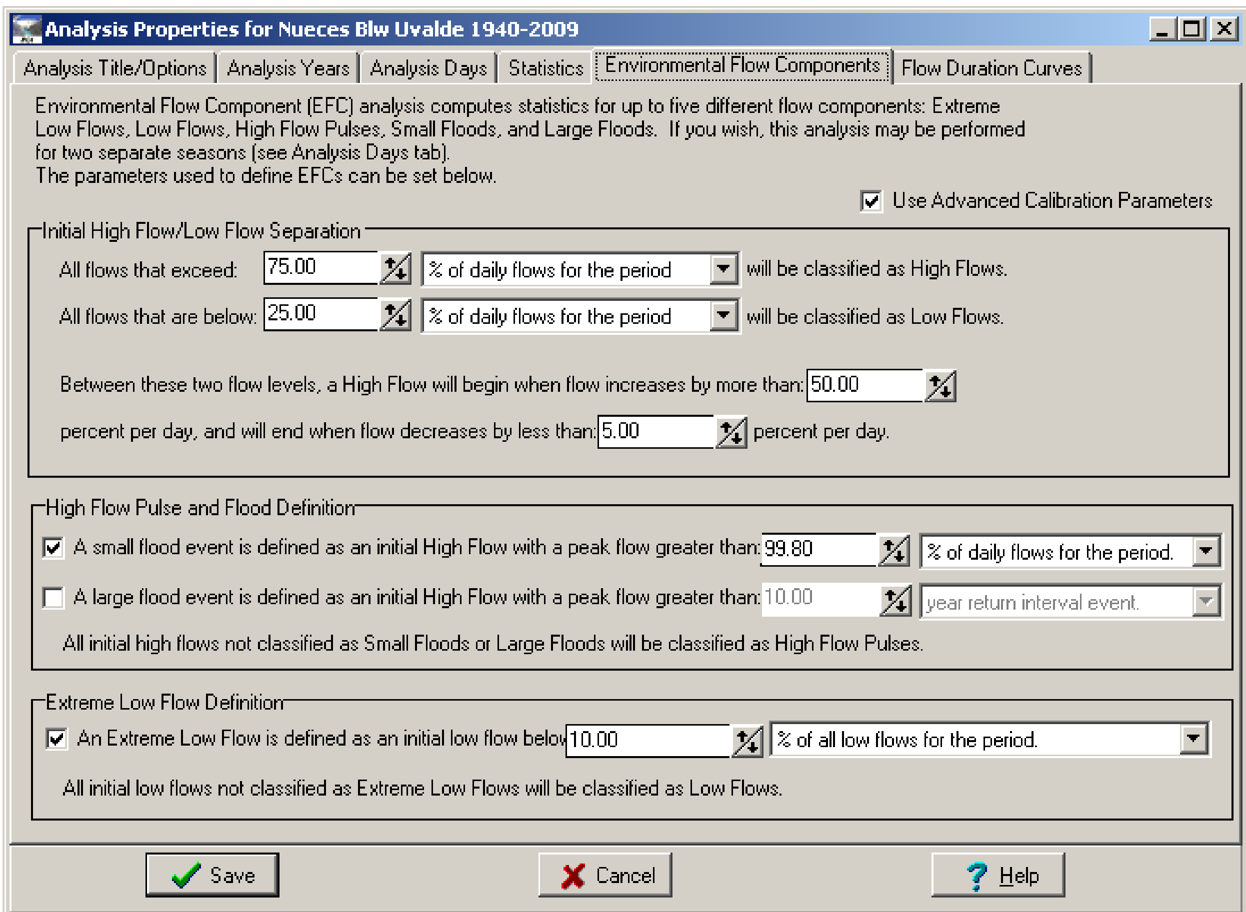

Figure 4. Screen Capture of EFC Tab in IHA

IHA sorts through all days in the period of record and assigns each date to one of two groups: (1) Group 1 contains potential subsistence and base flows, and (2) Group 2 contains potential high flow pulses and overbank flows (collectively referred to as episodic events). These assignments are performed using the first four parameters in Figure 4. The 75% designation for the first parameter forces IHA to classify all dates with flows in excess of the 75^{th} percentile (of all flows) to be in Group 2. The second parameter, the 25% designation, forces IHA to classify all dates with flows less than the 25th percentile (of all flows) to be in Group 1.

The third and fourth parameters are the rate of change parameters. These parameters are relevant only for dates with flows between the 25th and 75th percentiles of all flows. In this middle 50% of the flow record, any given date can be assigned to either Group 1 or Group 2, depending on the rate of change and the previous date's assignment. For Day i (i.e., any given day that is assumed to be between the 25th and 75th percentiles), if Day i-1 (i.e., the day before Day i) is a Group 1 day and the increase from Day i-1 to Day i is less than 50%, then Day i is also a Group 1 day. If this increase is greater than 50% then Day i begins a Group 2 event and is classified as a Group 2 day (i.e., a storm is assumed to occur between Day i-1 and i). Conversely for Day i, if Day i-1 is a Group 2 day, then Day i is also a Group 2 day, unless the flow from Day i-1 to Day i decreases by less than 5% in which case it is a Group 1 day.

At this point, the entire hydrograph is parsed into Group 1 and Group 2 days. Group 2 days are then distinguished using the fifth and sixth parameters in Figure 4. The fifth parameter sets the lower bound for overbank flows at the 99.8 percentile flow in this example application. This value is approximately 7,500 cfs. The NOAA action stage at this location is 10 ft.[19] The NOAA flood stage at this location is 11 ft. Based on an inspection of stage versus flow for data since 1/1/1995[20] (i.e., reasonably contemporary conditions), a stage of 11 ft is associated with a flow of 10,000 cfs and a stage of 10 ft is associated with a flow of 7,000 cfs. Thus, the 99.8 percentile daily flow is in the range of estimated overbank events. If desired, an inspection of instantaneous flow records compared to daily average flows could be used to further refine the relationship between daily average flows and events that may go over the bank for less than one calendar day. The sixth parameter is unchecked, effectively removing the "large flood" category from the hydrographic separation and forcing IHA to assign all flows in excess of the 99.8 percentile flow as one category of overbank flows ("small floods"). In this way, the large flood flow regime component is eliminated from the discussion and all storm events that are estimated to be greater than bankfull are incorporated in the overbank flow component.[21] The entirety of any Group 2 event (which consists of a consecutive series of dates based on the algorithm above) is classified as an overbank flow event if any day of the event exceeds the lower bound for overbank flows (99.8 percentile in this example). If no dates in the Group 2 event exceed this threshold, the entire event is classified as a high flow pulse. It is sometimes helpful to think of high flow pulses and overbank flows as events, in the sense that not all days exceed the bankfull condition (in the case of overbank), or even have particularly high flow rates (in both cases). This is by design, but if it conflicts with the professional judgment of the analyst, it can be ameliorated by different parameter selection.

[19] http://water.weather.gov/ahps2/hydrograph.php?wfo=ewx&gage=uvlt2
[20] http://waterdata.usgs.gov/tx/nwis/measurements/?site_no=08192000&agency_cd=USGS
[21] This is necessary because HEFR ignores IHA-classified "large flood" days.

Finally, the Group 1 days are distinguished using the last parameter in Figure 4. In this case, the bottom 10% of the Group 1 days are assigned to subsistence flows and the remaining 90% of Group 1 days are assigned to base flows.[22]

Figure 4.4-1 of the SAC Freshwater Inflow Regime document (SAC, 2009b) provides a schematic illustration of the IHA hydrographic separation logic. Additional descriptions of the logic can also be found in the "Hydrographic Separation Document" found on the TCEQ's Environmental Flows Resources webpage.

In this example, percentiles are used as user inputs to distinguish flow components. Version 7.1 of IHA now allows the user to directly input flow magnitudes (in cfs) instead of percentiles. This may be advantageous if the analyst knows that specific magnitudes of flow provide specific ecological functions.

To further explore possible distinctions between base flows and high flow pulses, Figure 5 shows a close-up of the hydrograph in late 1942. There are as few as two, or as many as four, events in Figure 5 that might be classified as high flow pulses.

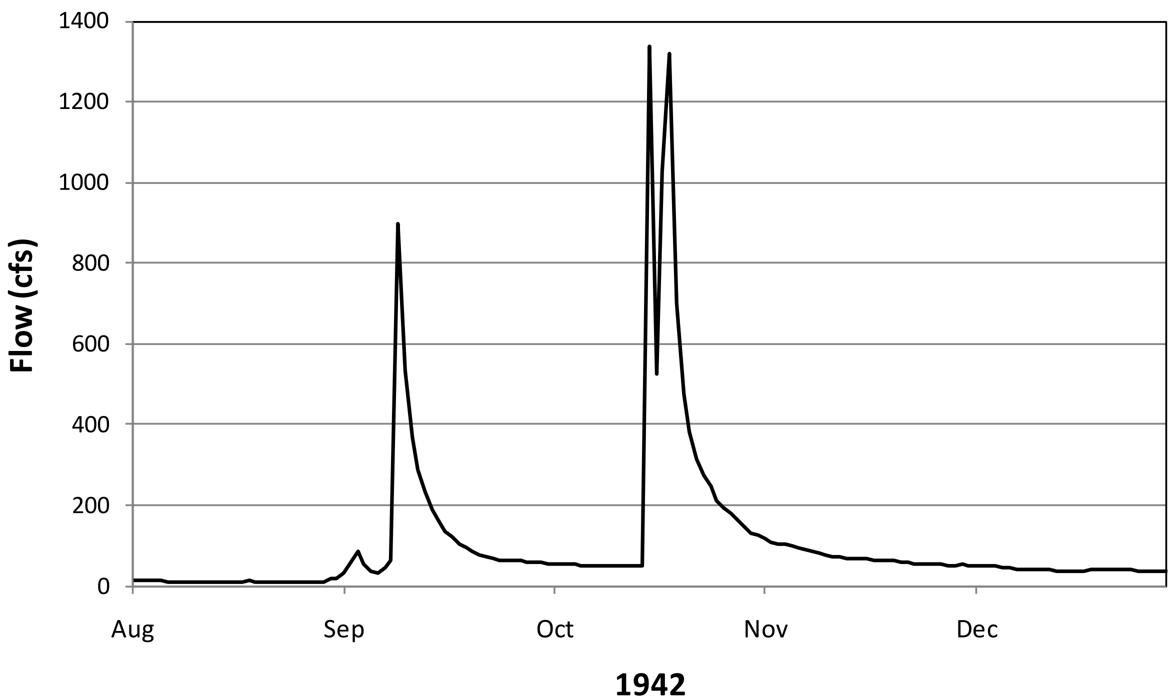

Figure 5. Hydrograph of Nueces River below Uvalde Gage, August 1, 1942 through December 31, 1942

[22] Note that in the newest version of IHA, the default percentile is "% of all flows for the period." Using the drop-down box, this must be changed to "% of all low flows for the period" as shown in Figure 4, if that is the desire of the analyst.

Using the EFC parameters listed above in Figure 4, Figure 6 shows the same data as Figure 5 with the flow regime components identified.[23] For reference, the 25th percentile of all flows (i.e., the lower threshold for high flow pulses) is calculated by IHA as 12 cfs, the median flow is 28 cfs, the 75th percentile of all flows (i.e., the upper threshold for high flow pulses) is 84 cfs, and the 99.8 percentile is 7,819 cfs. In Figure 6, the storm events appear to be reasonably well represented by the hydrographic separation algorithm. The first (small event) in very early September is categorized as an individual high flow pulse event. This event has a fairly small magnitude, duration, and volume. With a peak flow of 86 cfs, it barely exceeds the 75th percentile of all flows (84 cfs) but it is well above the lower threshold for high flow pulses (12cfs). The second, and larger, event in September 1942 is classified as a high flow pulse from the beginning of the peak through the first date where flow drops by less than 5% from one day to the next and the flow is equal to or below 84 cfs. The third event (October 1942) is classified identically. IHA does not classify a new high flow pulse unless/until a base flow day occurs. Thus, the second (slightly lower) peak in this October event (which occurred on the second day after the first peak) is not a new high flow pulse but rather continues the existing high flow pulse, because the intervening day exceeds 84 cfs and thus maintains the high flow pulse classification. While such events with multiple peaks cannot be disaggregated easily in IHA, HEFR does allow for the disaggregation (if desired) of multipeak high flow pulses and overbank events using the multipeaks_multiplier function.

Figure 6 does not illustrate subsistence or overbank flow components because the flows in this time period were not low or high enough, respectively.

[23] This figure was generated in Excel. IHA can conveniently generate similar figures; however the analyst must recognize that while IHA correctly provides flow regime component assignments in the tabular outputs, in the graphical outputs the color associated with a given date is actually based on the assignment of the previous day. This is a recognized minor bug in IHA (personal communication, Tom Fitzhugh).

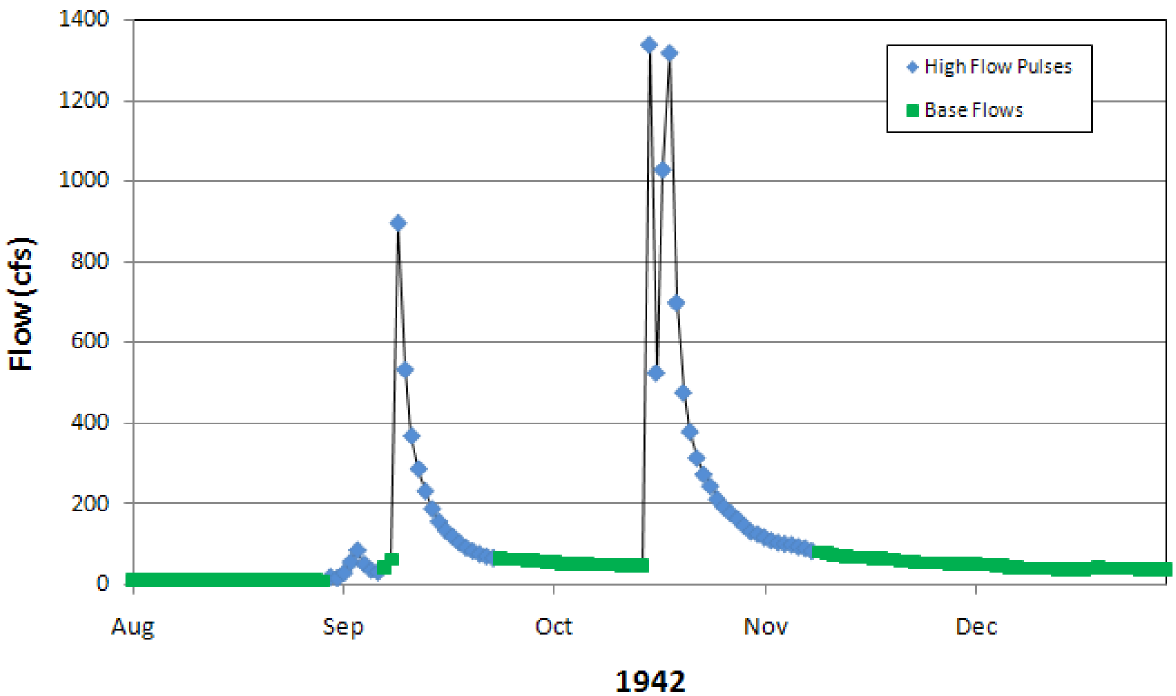

Figure 6. Nueces River below Uvalde Hydrographic Separation for 1942

Using these hydrographic separation parameters, subsistence flows are all flows at 1.5 cfs or below. These flows occur approximately 7% of the time (i.e., 1.5 cfs is exceeded 93% of the time) in the period of record. Base flows are between 1.6 and 84 cfs and occur approximately 65% of the time. High flow pulse events are between 13 and 7,390 cfs and occur approximately 14% of the time. Overbank events are between 15 and 51,600 cfs and occur approximately 14% of the time (note that 15cfs in itself is not an overbank flow but an overbank event may begin or end as low as 15 cfs).

While IHA does not have infinite flexibility to parse the hydrograph, the analyst can tune the EFC parameters to improve the separation, based on professional judgment. Alternatively, the analyst may choose to use the MBFIT hydrographic separation routine, which is available on TCEQ's Environmental Flows Resources webpage. It is recommended that the analyst carefully inspects the hydrographic separation and decide which method and parameter set is most appropriate for a given location and objective.

This example of the Nueces River below Uvalde presents interesting challenges to the hydrographic separation. The majority of flows at this location are low and steady, presumably the result of spring flows. Storm events in dry years are characterized by very rapid ascending limbs and fairly rapid descending (receding) limbs. Ideally, for the receding limbs, the primary consideration is what flow transitions from primarily high flow pulse ecological functions such as mobilizing sediments to base flow ecological functions such as instream habitat. This decision should be guided by various disciplines and site-specific information, if available. It is important to note that no attempt was made to employ such information in this example application.

Another interesting characteristic of this location is the irregular occurrence of extended high flow periods. Figure 7 illustrates the hydrograph (with the highest flows not shown) for 1987. In this year, the flow never fell below 84 cfs (the 75th percentile of all flows) and thus the entirety of this year is classified as an episodic event. Because the peak flow was 15,700 cfs on May 29, this entire event is classified as an overbank event. The HEFR multipeaks_multiplier algorithm could be used to split this long event into multiple distinct events. While the relatively low and steady flows in early 1987 could be the result of alluvial discharge and other short-flow-path groundwater discharges, these flows are relatively low only in the context of this wet year. These flows (on the order of 100-200 cfs) greatly exceed the typical condition for this location during this time of the year (closer to 30 cfs). Thus, while a traditional base flow separation algorithm may classify these as base flows, their magnitude suggests that their classification as part of a high flow pulse may be appropriate within the current context of hydrographic separation for ecological purposes.

Thus, to parameterize the EFC algorithm in IHA, several decisions must be made. The first important decision is whether or not the analyst desires the distinction between Group 1 and Group 2 days to be based primarily on magnitude, primarily on rate of change, or a balance of both. For example, if the analyst wants this distinction to be based primarily on magnitude, then parameters 1 and 2 are set close to each other (or even identically), at a level that the analyst believes approximates the ecological distinction between base flows and high flow pulses. Because parameters 1 and 2 are close to each other (or the same), the rate of change parameters are relevant to only a small portion (or none) of the hydrograph. If the analyst wants the distinction between groups 1 and 2 to be based primarily on rate of change, then the first parameter is set to a high value and the second parameter is set to a low value. In this case, a large fraction of the hydrograph is assigned based on the rate of change parameters. In the example provided here, 50% of the hydrograph is assigned solely due to the flow magnitude on that day and 50% of the hydrograph is assigned based on the rate of change. The 50% and 5% values (parameters 3 and 4) are selected, based on professional judgment, to have IHA classify rapid changes in flows in the high flow pulse category, while slower changes in flows tend to be assigned to the base flow category. This is with the expectation that rapid changes provide biological triggers associated with high flow pulses (e.g., spawning cues). In all cases, parameters should be selected with specific attention to the ecological roles of different flow values and patterns, rather than the hydrological sources of the water (i.e., runoff or groundwater discharge). It is very useful for an experienced and interdisciplinary team of scientists to look at several storm events, extended dry periods, and extended wet periods to ensure that the assignments are occurring as desired.

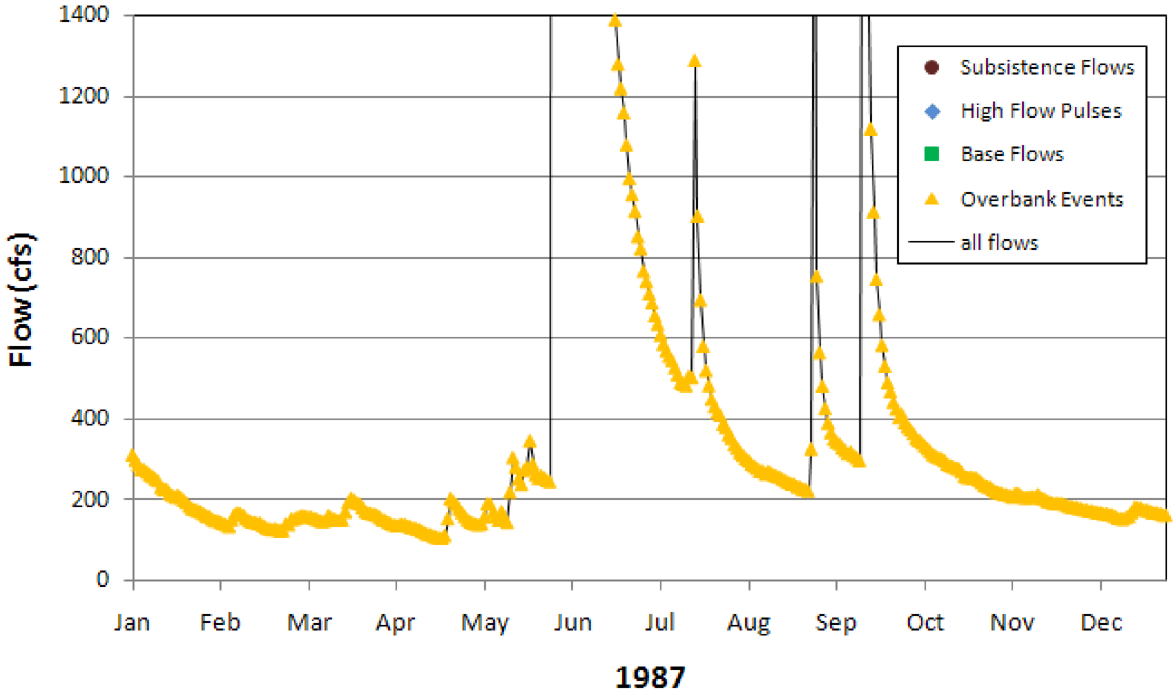

Figure 7. Nueces River below Uvalde Hydrographic Separation for 1987 (a wet year; all flows in this year are above the 75th percentile of all flows in the period of record)

The second important decision relates to the distinction between (in-bank) high flow pulses and overbank flows. Site specific data are very helpful here; it is possible that existing reports or a site visit and analysis may provide the flow magnitude associated with bankfull.[24] The National Weather Service (www.nws.noaa.gov) often has "action" and flood stage information associated with USGS flow gages. This stage information can be converted to flow using the USGS stage-discharge field measurements available on the USGS website. In the absence of site-specific or regional information, a return period similar to 1.5 years is often used.[25]

It is not expected that a single EFC parameter set would be applicable to all locations in Texas. Rather, some customization at the basin, or even sub-basin, level is to be expected. Different parameter sets, and/or different hydrographic separation algorithms, might be useful for locations with distinctive variations in flow characteristics or known ecology.

Using the selected parameters, IHA is run and the outputs are saved. While IHA generates a suite of hydrological statistics that prove useful to the analyst, the only IHA output that is used by HEFR is the information in the IHA table "daily efcs." This table contains the flow and EFC code for every day of the period of record.

[24] IHA uses daily average flows and some adjustments may be necessary if bankfull is determined using instantaneous flow data.

[25] IHA uses an empirical calculation of return interval and does not fit the hydrologic data to a distribution, e.g., as in USGS (1982).

5.2.4 Using HEFR

HEFR calculates summary statistics of the hydrographically-separated hydrologic data. HEFR is not a computer "model" because HEFR does not predict anything. Rather, HEFR is an algorithm that computes a variety of statistics based on user input. HEFR is an add-in to Excel that is available on the TCEQ's Environmental Flow Resources webpage. HEFR works with Excel2003, Excel2007, and Excel2010 on personal computers.[26] The analyst must download HEFR and add it as an add-in to Excel. This is done by copying the HEFR xla tool to a convenient location on your computer and installing as follows:

- Excel2003: Open Excel, select "Tools," "Add-ins," click on "Browse" and find the HEFR.xla file. Click OK. You should now have a HEFR menu.
- Excel2007: First, kick yourself in the shins for installing Excel2007. For good measure, kick yourself again. Swear that you will get Office2010 as soon as possible. Finally, consign yourself to your fate and open Excel, click on the office button (top left corner), "Excel Options," "Add-ins," in the "manage" drop-down box select "Excel Add-ins" and click "go," "Browse" and find the HEFR.xla file. Click OK. You should now have a HEFR menu in the "Add-ins" ribbon.
- Excel2010: Open Excel, click on the File Menu, then "Options," "Add-ins," in the "manage" drop-down box select "Excel Add-ins" and click "go," "Browse" and find the HEFR.xla file. Click OK. You should now have a HEFR menu in the "Add-ins" ribbon. If you get an error entitled "Object library invalid…" then try deleting all .exd files in this folder: "C:\Documents and Settings\USER\Application Data\Microsoft\Forms\" as described in http://www.lessanvaezi.com/delete-exd-files-to-fix-object-library-invalid-error/.

To provide a balance between integrity of the calculations and ease of use for the analyst, HEFR contains Visual Basic for Applications (VBA) code that is used to write Excel functions (where possible) and perform calculations directly (where Excel functions are inadequate). In this way the analyst can follow most of the calculations by examining the associated functions in Excel, but the analyst cannot inadvertently corrupt the original model itself.

To begin a HEFR run, the analyst starts with an Excel workbook containing the "daily efcs" output sheet from IHA. If the analyst used the MBFIT hydrographic separation algorithm, then the outputs must be formatted identically to an IHA "daily efcs" worksheet.

The following paragraphs loosely follow the structure shown in the decision tree (Figure 3).

Assignment Period (Seasonality)
HEFR generates results on a monthly and/or seasonal basis (see below). The user can select an arbitrary number and length of seasons. For this example, the seasonal assignments are as

[26] Excel2008 for the Macintosh does not support VBA and thus HEFR will not work on this platform.

follows: Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug), and Fall (Sep-Nov). This is the default seasonality in HEFR. When selecting seasons, the analyst should consider grouping months with flows and temperatures that might provide consistent ecological cues and functions.

Calculations Using Non-Zero Flows Only
HEFR has an option to calculate subsistence and base flow recommendations using solely non-zero flow days. If this option is selected, it is important for decision makers to know, because it changes the attainment frequency interpretation of the flow recommendations. Also, it is expected that the historical frequency of zero flow days would be incorporated into the flow recommendations, perhaps as a basis for recommending future frequencies of zero flow days. In this example, this option was not selected; therefore all of the days, including those with zero flow, were used in the calculations. A comparison to HEFR results with this option turned on is provided later in the document.

Subsistence Flows Method
HEFR includes two computational methods for subsistence flows, plus an override setting. The first computational method sets the subsistence flow recommendation at a user specified percentile of the IHA-classified subsistence flow days for the given month or season. The default percentile is 0.5 (corresponding to the median). The second computational method is a monthly and seasonal Q95, which is the 5th percentile (95% exceedence level) of all flows in the month or season (i.e., without regard to hydrographic separation). Q95 has been discussed and used in the literature (Acreman et al., 2006; Hardy et al., 2006; BIO-WEST, 2008) and was considered by the Sabine-Neches BBEST. The override is an optional "water quality protection flow." If the user enters a value in this input box then any computations that result in a lower value are replaced with the water quality protection flow value.

For this example, the median of subsistence flows was selected and the water quality protection flow input box was left blank.

Subsistence flows recommendations are generated in HEFR on a monthly and seasonal basis. The analyst can choose to use either.

Base Flows
There are three possible levels of base flows: low, medium, and high. Each is assigned a percentile and the flow recommendation for a given month or season is the user-specified percentile of all IHA-classified base flow days for that month or season. Default values are 0.25 (i.e., 25th percentile), 0.5, and 0.75 for low, medium, and high respectively.

Base flows recommendations are generated in HEFR on a monthly and seasonal basis. The analyst can choose to use either.

Multipeaks_Multiplier
While the majority of the hydrographic separation task is performed in IHA or MBFIT, neither of these methods can split multiple storm events into multiple high flow pulses unless separated by a base flow day. Because of the importance of statistical calculations on high flow pulses in HEFR outputs, it may be appropriate to split high flow pulses with multiple individual peaks

(i.e., caused by distinct storm events) into individual high flow pulse events. HEFR can do this using the multipeaks_multiplier option.

The HEFR multipeaks_multiplier algorithm works as follows. When, in the midst of a high flow pulse that has declined from its initial peak flow rate, the flow increases from Day i-1 to Day i by more than 100% (if multipeaks_multiplier is set to 2), a new high flow pulse is designated in HEFR. In this way, a long high flow pulse is broken into a series of shorter high flow pulses. Because overbank enents are simply high flow pulses where one or more days exceed the bankfull flow value, overbank events can also exhibit the same behavior and can be separated using the multipeaks_multiplier for overbank events. It should be noted that when the multipeaks_multiplier is used to split up a long overbank event, each individual piece is classified as an overbank event, even if that piece would not qualify as an overbank event on its own. Because of the way the statistics are calculated, this potential problem is irrelevant if the user selects the Frequency Approach for episodic events and is only a concern if the user selects the Percentile Approach for episodic events.

When contemplating the use of the multipeaks_multiplier option, the analyst should carefully consider if there actually is a problem to be solved. Long high flow pulses and overbank events may be appropriate for a particular location and may not need to be separated. The analyst should also evaluate if long high flow pulses and overbank events are caused by multiple discrete storms or a single storm across tributaries with different travel times.

Episodic Events Method

HEFR has two methods for developing flow recommendations for episodic events: the percentile approach and the frequency approach. In this example, the frequency approach is used. Both methods are described in a subsequent section of this document.

Based on the selections shown in Figure 8, HEFR performs the following calculations.

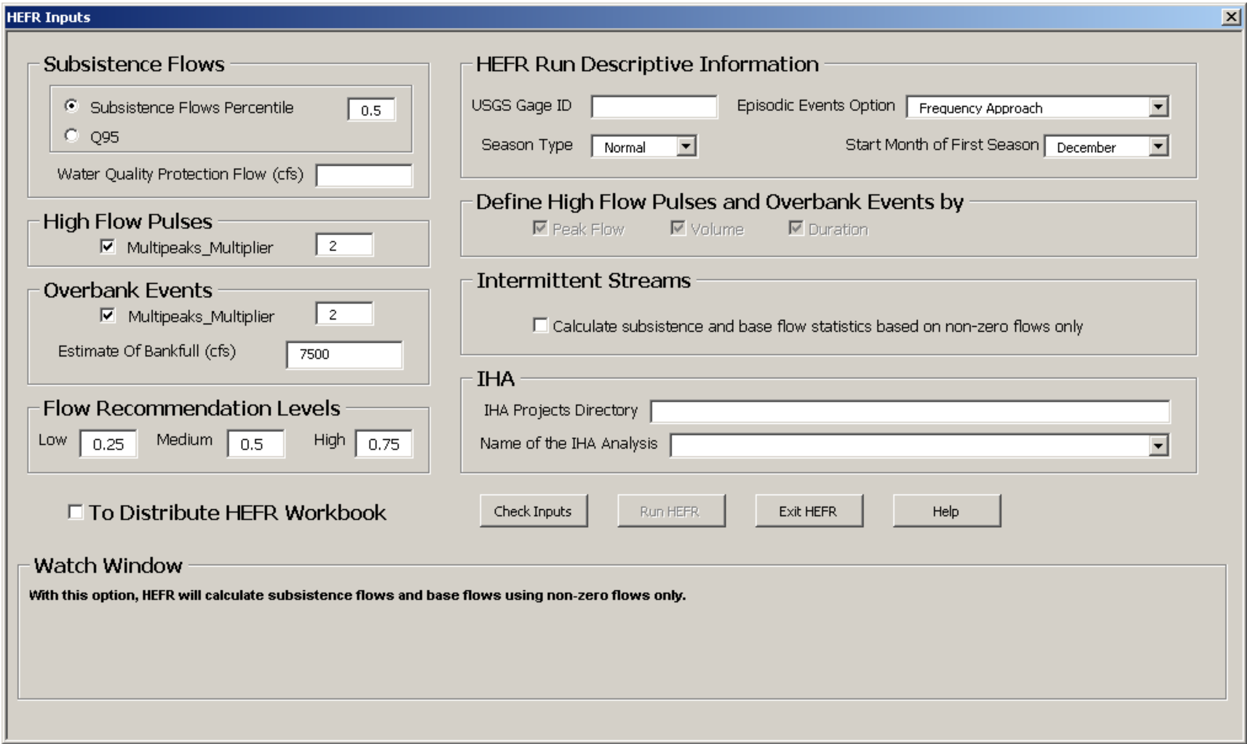

Figure 8. HEFR Inputs for the Nueces River below Uvalde Example

Subsistence Flows

All subsistence flows are binned by month and the median (in this example) for each month is calculated. The recommended subsistence flow is the greater of this calculated flow and a user-input "water quality protection" flow. In this example, no water quality protection flow is entered (i.e., the value is left at zero). If the user leaves the value of zero for the water quality protection flow and no subsistence flows have occurred in a given calendar month over the entire period of record, then HEFR posts the text "N/A" for "not applicable" in the flow matrix for that month. This sometimes happens in spring months where subsistence flows (as defined by the hydrographic separation parameters and algorithm that the analyst used) do not occur. These calculations are also performed seasonally in addition to monthly.

The HEFR Excel sheet "Baseflows" contains a table of the count of subsistence flow days by month. The user should examine this table to judge the reasonableness of subsistence flow recommendations in the event that only one, or a very few, subsistence flows were identified in a given month. For example, even if only one subsistence flow day was ever identified in the month of April over the period of record, that one day would become the subsistence flow recommendation (assuming its value is greater than the user-input water quality protection flow). This dependence of the flow recommendation on a single daily flow value is undesirable and should be carefully considered.

HEFR calculates several statistics related to zero flow events and events below subsistence flow recommendations. In sheet "ZeroFlows," HEFR provides (1) a listing of historical zero flow "events" (i.e., all periods of zero flows), (2) historical frequency of zero flows days, calculated both annually and seasonally, (3) minimum, median, and maximum duration of historical zero flow events, calculated both annually and seasonally, and (4) historical average number of zero flow events per year and per season. In sheet "SubsistenceDurations," HEFR generates similar statistics for events equal to or below the subsistence flow recommendation for each season.

Base Flows

All base flows are binned by month and the minimum, 25th percentile, 50th percentile, 75th percentile (i.e., 25th, 50th, and 75th in this example; these percentiles are input by the user), and maximum for each month are calculated. The 25th, 50th, and 75th percentile base flows are labeled low, medium, and high, respectively. These labels are simply used as a convenience and qualitatively refer to the flow rate associated with each level. These labels do not refer to the habitat quality or other biological characteristics associated with these flows. In all cases, if the HEFR-calculated base flow value is less than the user-entered "water quality protection flow," then the water quality protection flow is used in the final HEFR matrix.

The HEFR output matrix includes percent values (in parentheses) below each subsistence flow and base flow result. These values denote the historical exceedence frequency of the flow magnitudes based on the unseparated dataset.

High Flow Pulses and Overbank Events

This section describes application of the Frequency Approach for high flow pulses and overbank events. Details regarding this approach, and a second approach called the Percentile Approach, are discussed later in this document.

In this example application, the default 68.3 percent confidence interval is used. This results in prediction intervals around the best-fit regression line that incorporate approximately 68.3% of the data, which is equivalent to plus/minus one standard deviation in cases where the residuals are normally distributed.

HEFR allows the user to (optionally) enter their best estimate of bankfull at the location. If the user does so, HEFR will warn the user if the overbank event magnitude selected by the user is less than bankfull. Similarly, HEFR will warn the user if any high flow pulse magnitude selected by the user is greater than bankfull. For this example, it was judged that a flow of 7,500 cfs corresponded to bankfull and hence the overbank event was chosen to be greater than this value and all high flow pulses were chosen to be less than this value. For this example, the overbank event was set to the 1 per 5 years size and the high flow pulse tiers included the 1 per year, 2 per year, and 1 per season events. For this location and the parameter options selected, high flow pulses did not historically occur at a rate of 2 per season, so these events were not available to be specified.

HEFR allows for the selection of one overbank event and up to five high flow pulse tiers. Optimally, information from biologists and other scientists is used to identify desired flow magnitudes and the HEFR frequency chart is used to assign an appropriate frequency to each event size. In practice, if HEFR is being run before enough biological information is available, the analyst can enter a range of high flow pulse tiers with the expectation that additional HEFR runs incorporating more biological information may be necessary at a later date.

The Frequency Approach in HEFR uses regressions between episodic event volumes versus peak flows and durations versus peak flows to generate volume and duration recommendations. HEFR provides two regression options, ln/ln and quadratic, with the expectation that the analyst will select the regression form with the better fit in the vicinity of each peak flow recommendation. A visual inspection of the regression results and residuals in the vicinity of the episodic event recommendations led to the following decisions:

- 1 per 5 year event (18,500 cfs)
  - Volume: The ln/ln regression is biased low. The quadratic regression was selected.
  - Duration: The quadratic and ln/ln regressions are similar and reasonable. The quadratic regression was selected.
- 1 per year event (2,460 cfs)
  - Volume: The quadratic and ln/ln regressions are similar and reasonable. The quadratic regression was selected.
  - Duration: The quadratic and ln/ln regressions are similar and reasonable. The quadratic regression was selected.
- 2 per year event (435 cfs)
  - Volume: The ln/ln regression is biased low. The quadratic regression was selected.
  - Duration: The ln/ln regression is biased low. The quadratic regression was selected.
- 1 per Spring season event (28 cfs)
  - Volume: The quadratic regression is biased high. The ln/ln regression was selected.
  - Duration: The quadratic regression is biased high. The ln/ln regression was selected.
- 1 per Summer season event (65 cfs)
  - Volume: The quadratic regression is biased high. The ln/ln regression was selected.
  - Duration: The quadratic regression is biased high. The ln/ln regression was selected.
- 1 per Fall season event (51 cfs)
  - Volume: The quadratic regression is biased high. The ln/ln regression was selected.
  - Duration: The quadratic regression is biased high. The ln/ln regression was selected.

These decisions are based solely on the best-fit line. In some cases, the bounds defined by the prediction intervals are unrealistic. If the prediction intervals are deemed important, additional examination would be necessary.

It is important to remember that a regression equation attempts to fit all of the data, often at the expense of some of the data. As an example of how a best fit regression line may not fit the data in the vicinity of interest, Figure 9 shows the quadratic regression results for the volume versus peak flow for Spring events in the vicinity of the 1 per Spring season recommendation (28 cfs). The data show a slightly increasing trend with peak flow. Unfortunately, the best-fit regression (red line) is several times higher than the data in this portion of the dataset. Furthermore, the lower prediction interval bound is negative (which is physically impossible) and the upper bound (green line) is at a value of approximately 100 times the data. These results demonstrate why the regressions should be carefully examined when volume and/or duration characteristics of high flow pulses are desired to be included in flow recommendations.

In the current version of HEFR, the flow regime component characteristics of high flow pulses and overbank events that are delineated are peak flow, duration, volume, and frequency. Statistics describing the rise rate and fall rate are not included.

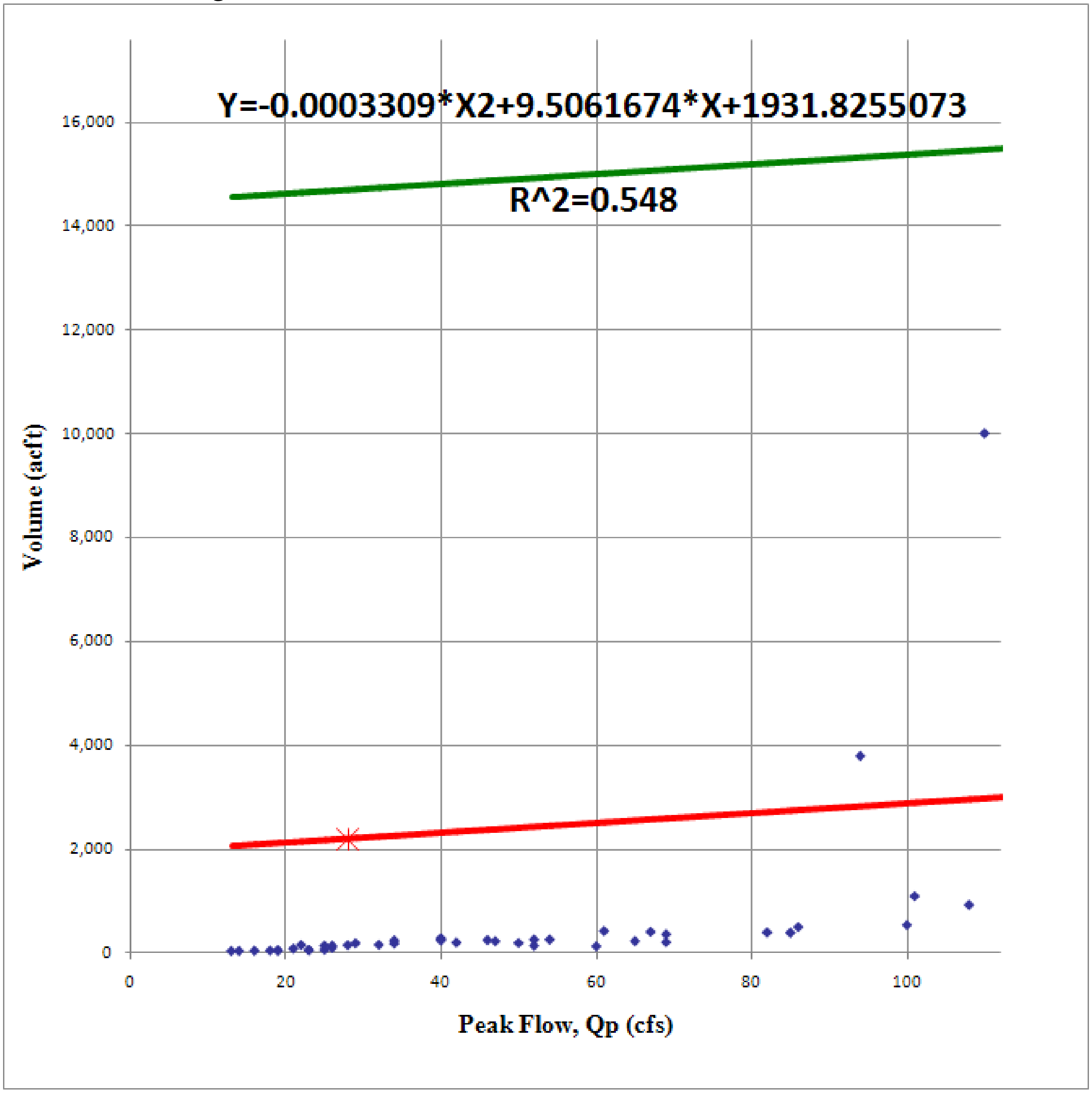

Figure 9. Volume versus Peak Flow Regression in Vicinity of 54 cfs.

5.2.5 Example Outputs

Figure 10 shows the resulting populated flow regime matrix for the Nueces River below Uvalde example. HEFR forces the analyst to choose either the ln/ln regression or the quadratic regression for volume and duration in any given run. Because the decisions listed above combined both regression forms for various tiers, the matrix shown in Figure 10 is actually a combination of two separate HEFR runs.

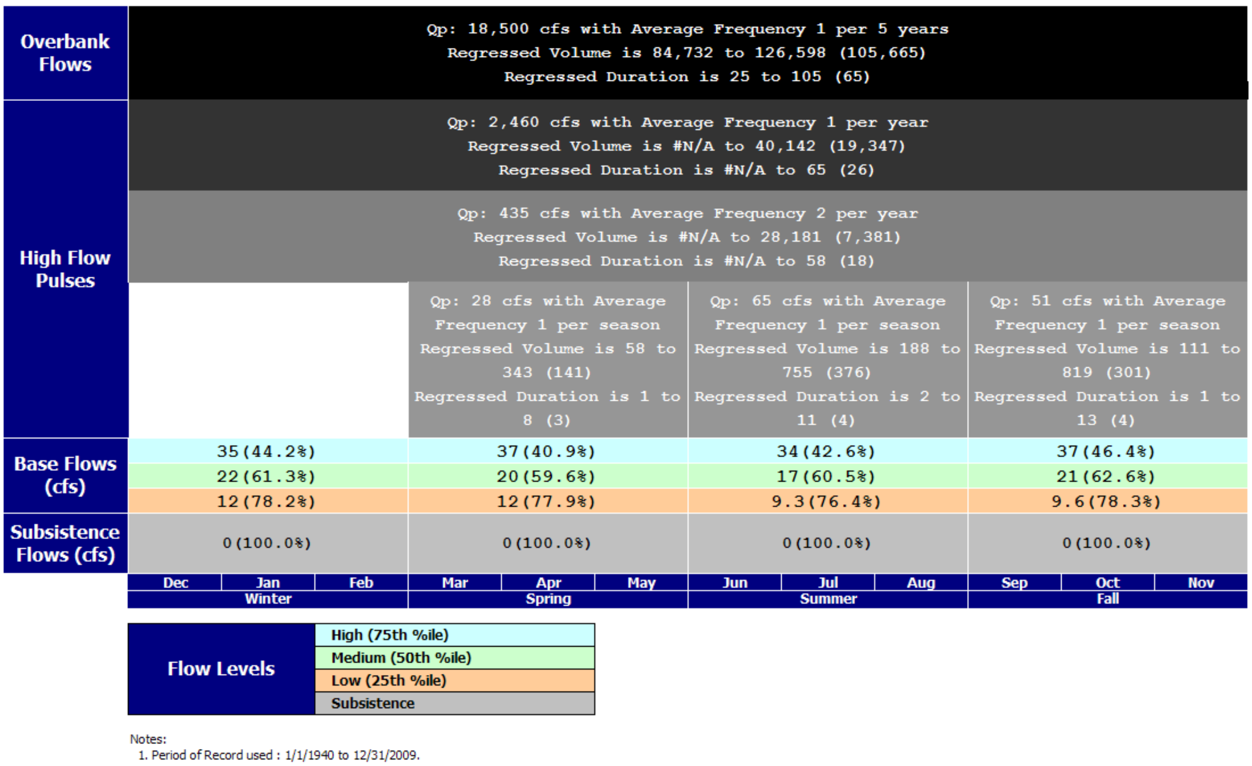

Figure 10. Example HEFR output for Nueces River below Uvalde

For the subsistence and base flows, the first number is the flow recommendation in cfs whereas the second number (in parenthesis) is the historical frequency that that flow was equaled or exceeded in the unseparated flow dataset (see discussion on subsistence flows below).

For the high flow pulses and overbank events, the volume and duration ranges listed are the lower and upper prediction intervals, with the regression best-fit provided in parenthesis.

It is interesting to note that the spring season high flow pulse (Figure 10, with peak flow of 28 cfs) is actually smaller than the spring "high" base flow recommendation. This indicates that there is significant overlap in the hydrographic separation between the base flow and high flow pulse components. In a real-world application of HEFR, further examination of the hydrographic separation may be warranted.

The 1940-2009 dataset contains about 6% zero flow days. Subsistence flow recommendations are based on the median (i.e., the 50th percentile) of the bottom 10% of the initially identified base flow days. If all days in the period of record were identified as base flow days, then the subsistence flow recommendation would be the 5th percentile of the dataset. Because some days are classified as high flow pulses, the subsistence flow recommendation will be less than the 5th percentile of the dataset. Given that the seasonal subsistence flow recommendations will be less than the 5th percentile by season, but there are more than 5% zero flow days, the subsistence flow recommendations are all zero. This HEFR matrix does not reflect: (1) the actual percentage of historical zero flow days, which may be important to a recommended flow regime, and (2) the percentage of days with flow, but below the low base flow recommendations. This type of information is not included in the main HEFR output matrix, but is available in the ancillary output tables. For example, Figure 11 shows the frequency of zero flow days (binned by season), and the minimum, median, and maximum duration of zero flow events (binned by the season of the start of the event).

Period	Frequency of zero flow days within period	Duration of zero flow events (days; entire duration assigned to period of start of event)		
		Minimum	Median	Maximum
Annual	6.40%	1	127	417
Winter	6.98%	216	316.5	417
Spring	7.70%	1	1	1
Summer	6.13%	28	86.5	403
Fall	4.79%	4	98	199

Figure 11. Example HEFR Zero-Flow output for Nueces River below Uvalde

Another HEFR output table (not shown) lists the eleven individual zero-flow events that occurred in the period of record, including their individual start dates and durations. Collectively, these results show that, at this location, zero-flow events rarely start in the spring, start most frequently in the summer and fall, and can last in excess of one year. Because long events that start in the summer and fall can extend into the following spring, zero-flow days are fairly equally distributed by season. In addition, all zero-flow days occurred in the 1950s. This location has been perennial since April 19, 1957.

Because of the existence of such zero-flow events, this gage would be a good candidate to consider using the “non-zero flows option” discussed below in this document.

Similar tables are provided that describe the frequency and duration of subsistence flow events (i.e., consecutive days equal to or below the subsistence flow recommendations).

5.3 HYDROLOGIC DECISIONS NOT NEEDED TO RUN HEFR

The interpretation- and implementation-focused decision points listed below are necessary for a realistic application of the HEFR methodology, but are not needed to simply run HEFR. Accordingly, these were not discussed in the Uvalde example given above.

Geographic Scope of all Instream Flow Recommendations and Spatial Extent of Individual Instream Flow Recommendations
Number and Location of Control Points
Flow Recommendations in the Absence of a Flow Gage

In a given application of HEFR, only one flow gage is used. Therefore any decisions regarding the geographic scope of all instream flow recommendations, the spatial extent of individual instream flow recommendations, the number and location of control points, and how to synthesize data at a location without a flow gage, are made outside of the HEFR methodology.

Memory

Memory from one assignment period to the next is conceptualized as an interpretation and implementation question and is not included in any HEFR calculations. Interpretation of HEFR outputs should be closely informed by the statistical approaches and data used to generate the outputs. For example, if a high flow pulse has historically occurred, on average, once per year, then it would make sense to recommend this size pulse at a frequency of once per year (or less), on average. A recommendation that this sized pulse occur once per year, every year, would be difficult, if not impossible, to fulfill.

Daily Average Versus Instantaneous Flow Data

The HEFR methodology solely uses daily average flow data.

Hydrologic/Climatic Condition – Trigger

As discussed above, HEFR outputs subsistence flows, three levels of base flows, and up to several tiers of high flow pulses. Depending on implementation considerations, these may be conceptualized as applying during various hydrologic conditions. However, since this is largely an implementation issue, HEFR does not consider potential triggers that would define these hydrologic conditions.

5.4 HYDROGRAPHIC SEPARATION – ADDITIONAL DISCUSSION

A defining characteristic of HEFR that distinguishes it from many other hydrologic methods for establishing environmental flow recommendations is an initial hydrographic separation step. Hydrographic separation is used to categorize each day of the period of record as one flow component.[27] It is also important to remember that HEFR presupposes that the days in episodic storm events are classified on an event basis: all of the days in an entire event are classified as high flow pulse if the event meets the requirements of a high flow pulse. Similarly, all of the

[27] In the current version of HEFR, these flow components are subsistence flow, base flow, high flow pulse, and overbank events. Other options could be used. Note that the IHA software uses the terminology "flow component," even though, as pointed out in Ward (2009), since each day gets one and only one such assignment, these might more appropriately be termed categories or classes. Because of the variability of terminology in the literature, in this document and context, the words component, category, and classification will be used interchangeably.

days in an entire storm event are classified as overbank if the event meets the requirements of an overbank event (i.e., not solely those individual days that are "over the bank").

In this section, hydrographic separation concepts are discussed more fully. The IHA EFC and MBFIT algorithms are briefly summarized and example results are provided and described.

5.4.1 Hydrographic Separation Concepts

Hydrographic separation is the science (and art) of distinguishing between different flow classes (or components). Traditionally, hydrographic separation is termed base flow separation and focuses on distinguishing between sources of flow, e.g., between groundwater derived flow (usually termed base flow) and storm event derived flow (usually termed runoff). However, terminology and conceptual models vary depending on project objectives. Indeed, a wide range of flow sources could be identified, from long-term regional groundwater flow paths, to shorter interflow through the soil, discharge from alluvial aquifers, and direct precipitation on the stream surface. Distinguishing between these sources of water is frequently important in traditional hydrologic and water resources studies. Useful references include Ward (2009), Smakhtin (2001), Chapman (1999), and Eckhardt (2008).

For the purposes of establishing an appropriate environmental flow regime in the context of Senate Bill 3, multiple flow components are desired, some of which are at least partially derived from groundwater or alluvial sources (subsistence and base flows) and some of which are more a result of storm events (high flow pulses and overbank events). Because of the focus on ecosystem function, the traditional distinction between various groundwater and runoff sources does not necessarily fit in the context of environmental flow recommendations. For the purposes of SB 3 efforts, it is less important to identify the source of water than the ecological role, function, or significance, of varying flow magnitudes and other flow characteristics. Put simply, the hydrographic separation in HEFR is a hydrological activity for an ecological purpose and is therefore not synonymous with traditional base flow separation methodologies. In the development and application of the EFC algorithm in IHA, one consideration for the use of the term "low flow" in lieu of "base flow" has been to avoid the traditional connotation of "base flow" being purely groundwater derived (Ryan Smith, personal communication). In this light, it is more desirable to separate the hydrograph into biologically and ecologically meaningful components than components based on the water source. A description of the primary objectives of the different flow components considered important for describing environmental flow prescriptions as used in HEFR is provided in Section 2.2.

For efforts associated with SB3, it is important to identify the ecologically and biologically important components of the flow regime to develop recommendations that provide ecological benefits such as those listed in Section 2.2. Very small runoff events, while classified as runoff by traditional hydrographic separation algorithms, may not provide any of the ecological benefits associated with high flow pulses. Similarly, during the leading and trailing limbs of storm hydrographs, fish may not be hiding in velocity shelters and may be exploiting habitats made available by these flows. Thus the ecological role of some leading and trailing limbs may be more akin to base flows than high flow pulses. Conversely, high flows, even if sustained for a period, may not serve the habitat functions of base flows, even if identified as base flows by a particular hydrographic separation algorithm (e.g., as many happen if such flows are fairly steady) . The ecological functions associated with the various flow conditions may be primarily dependent on flow rate, but may also be dependent on volume, timing, rate of change, and duration (e.g., to move significant sediments, higher flows for sustained periods may be required).

Because of these complexities, it is helpful to define a conceptual model of the various hydrographic flow components that are known to play important roles in supporting a sound ecological environment in a particular stream segment before completing a hydrographic separation analysis. The varying ecological characteristics of different stream segments are likely to require different definitions of flow components in order to achieve appropriate environmental flow prescriptions with HEFR.

There are currently two options for hydrographic separation that can be used in HEFR, both of which have user-defined options to provide flexibility. These are termed (1) IHA and (2) MBFIT and are discussed below.

5.4.2 IHA EFC Method

As discussed in the Uvalde example above, IHA parses the hydrograph using a combination of flow magnitude and rate of change parameters, seven in total. These parameters can be tuned to the location of interest, based on project objectives. For example, the HEFR default IHA EFC parameter set (given in Figure 4) has fairly high rate of change parameters (50% increase and 5% decrease) for initiating and terminating high flow pulses. This is often appropriate for flashy systems that change rapidly. Lower values may be appropriate for less flashy systems.

The HEFR default values of the 25th percentile and 75th percentile for the lower and upper high flow pulse thresholds results in 50% of the hydrograph being specified on flow magnitude alone, and 50% being specified on rate of change.

5.4.3 Modified BFI with Threshold Method (MBFIT)

The Base Flow Index Method of the U.S. Bureau of Reclamation[28] has been used to separate hydrographs into base flow and runoff components, where every day is assigned some amount of base flow and some days additionally have runoff flow. The method is based upon dividing the daily time series of flows into N-day windows and tracking the time series of minima in each window. The window length N is at the disposal of the user and is considered a measure of the time for a storm hydrograph to substantially recede. In this respect, the BFI approach has some kinship with the traditional base flow separation techniques relying upon recession time-series behavior (details are given in Wahl and Wahl, 1995). This is a purely empirical approach whose justification is based upon post facto applications, where the BFI seems to capture what is believed to be base flow behavior.

[28] http://www.usbr.gov/pmts/hydraulics_lab/twahl/bfi/

A modification of this method has been developed in Excel for use by HEFR. This modification differs from the BFI method in three respects: (1) rather than subdivide the daily flow time series into N-day windows, it uses a sliding centered window of N-day length, so each day of the time series has an associated window-minimum value, (2) the interpolation between "turning points" to create a base flow time series has been omitted because it is irrelevant to the one day – one category concept used in HEFR, and (3) upper and lower thresholds (similar to the magnitude thresholds in IHA) have been added that force the code to always assign a day to the high flow pulse or overbank categories if the flow exceeds the upper threshold (UT) and to never assign a day to the high flow pulse or overbank categories if the flow is less than the lower threshold (LT). The basic functioning of the algorithm is as follows: if the daily flow in excess of the associated minimum of (1) is less than the associated minimum of (1) times the parameter RF (Runoff Fraction, RF<1), that day is initially classified as a base flow, unless the flow exceeds the upper threshold.

This calculation approach typically has a large emphasis on rate of change and a lesser emphasis on flow magnitude when making distinctions between base flows and high flow pulses. This behavior can be lessened at the discretion of the analyst by increasing the lower threshold for high flow pulses and decreasing the upper threshold.

In the MBFIT method, subsistence flows and overbank events are coded in similarly to the IHA EFC algorithm. Following the default HEFR parameter set, subsistence flows can be identified as the lowest 10% of the initially-classified base flows (i.e., the MBFIT method initially classifies each day as either a base flow or a high flow pulse. The bottom 10% of these initially classified base flow days then becomes subsistence flows.). Similarly, initially-classified high flow pulse events that exceed the 1.5 year return flow are then classified as overbank flow events. These parameter values (10% and 1.5 year) are adjustable by the user.

These upper and lower thresholds can be "turned off" by setting the upper threshold to 100% and the lower threshold to 0%. In this case, only the BFI sliding window calculation controls the results.

Some possible weaknesses of the MBFIT method in the context of ecological goals are that very small runoff events are frequently assigned to the high flow pulse category, flow "valleys" between adjacent storm events are often classified as base flows (even if these occur at relatively high flow magnitudes), and occasionally flow days near the top of long storms are assigned to the base flow category. Careful selection of the N, RF, LT, and UT parameters can reduce the occurrence of these potential problems, which are illustrated in the following section.

5.4.4 Comparison between Various Parameterizations of IHA and MBFIT

In this section, the Nueces River below Uvalde is examined to illustrate the behavior of the two hydrographic separation methods with a few different parameter values. This discussion is far from comprehensive and is intended to serve as an informal sensitivity analysis to compare and contrast the two methods with a few different parameter sets.

Figure 12 shows the hydrographic separation results for Nueces River below Uvalde for the relatively dry year of 1943. In this simulation, data from January 1, 1940 through December 31, 2009 were entered into IHA and hydrographically separated. The bottom panel represents the parameter set for the HEFR-Def-OB (HEFR Default with site-specific overbank) data series as shown in Figure 4 above[29]. The parameter set for the IHA-TO-OB (IHA Threshold Only, with site specific overbank; middle panel) data series uses a magnitude-only distinction between base flows and high flow pulses at the 75th percentile. Rate of change parameters are not used. The upper panel shows the results using MBFIT with the parameter set used by the Sabine-Neches BBEST at the Big Cow Creek near Newton site with the addition of the site-specific overbank value (MBFIT-BC-OB). The Big Cow Creek parameter set was selected because it is a relatively small drainage (and a relatively small N value was used).

Salient characteristics of the results include:

1. The IHA-TO-OB simulation (middle panel) did not identify any high flow pulses in 1943 because the flows remained below the 75th percentile of all flows (84 cfs) for the entire year. In the 1940-2009 period, this simulation identified 203 discrete episodic events.
2. The IHA HEFR-DEF-OB simulation (bottom panel) identified 5 distinct high flow pulses, the smallest of which had a peak flow of 26 cfs (corresponding to the 48th percentile of all data). In the 1940-2009 period, this simulation identified 295 discrete episodic events.
3. The MBFIT-BC-OB simulation (top panel) identified 21 distinct high flow pulses (seven of which are one day long), the smallest of which had a peak flow of 10 cfs. In the 1940-2009 period, this simulation identified 1,018 discrete episodic events (>3x either of the other methods).

[29] Note that this is labeled HEFR-Def even though HEFR is not used in the generation of these figures. Only IHA is used, however, IHA is parameterized using the suggested HEFR default values (see Appendix A), thus the nomenclature HEFR-Def.

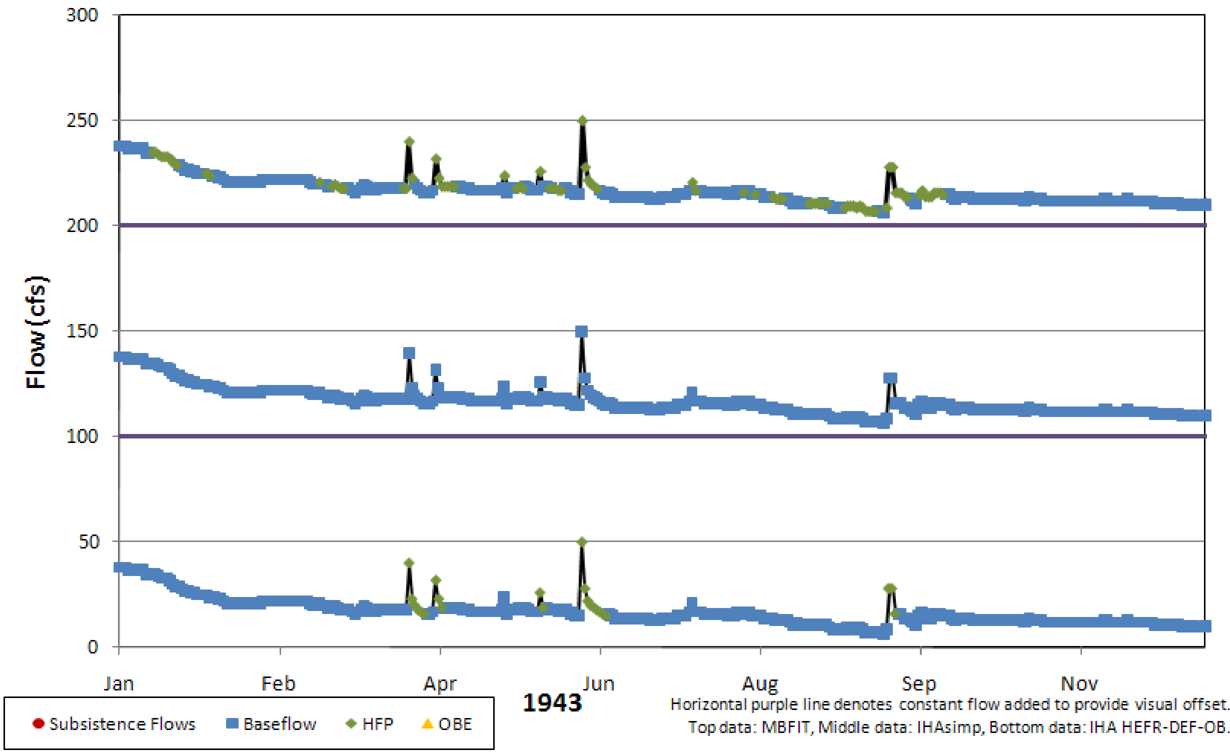

Figure 12. Comparison of Hydrographic Separation Methods for 1943

A zoom in on August of 1943 is illustrative. Figure 13 shows four high flow pulse events using the MBFIT separation algorithm (top panel), none of which appear to be driven by storm events or are likely to provide the ecological functions associated with high flow pulses (as there is no "pulse"). These are identified as high flow pulse days because the day in question exceeds the estimate of base flow for the N day window.

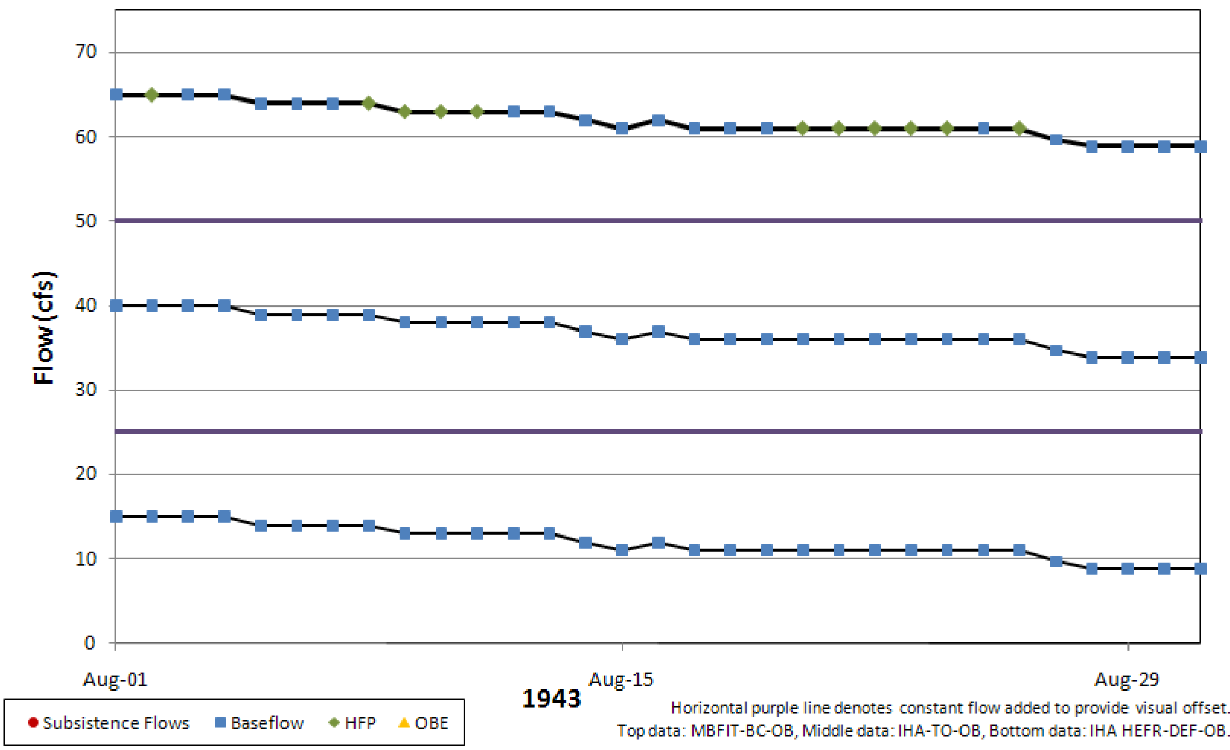

Figure 13. Close Up of Hydrographic Separation Methods for August 1943

Figure 14 illustrates the results for 1949, a more average year with several storm events. Again, the MBFIT result identifies more high flow pulses and also classifies more of the storm "tails" as high flow pulses than the IHA approaches. Figure 15 illustrates the hydrographic results for 1975, which is a more consistently wet year than 1949.

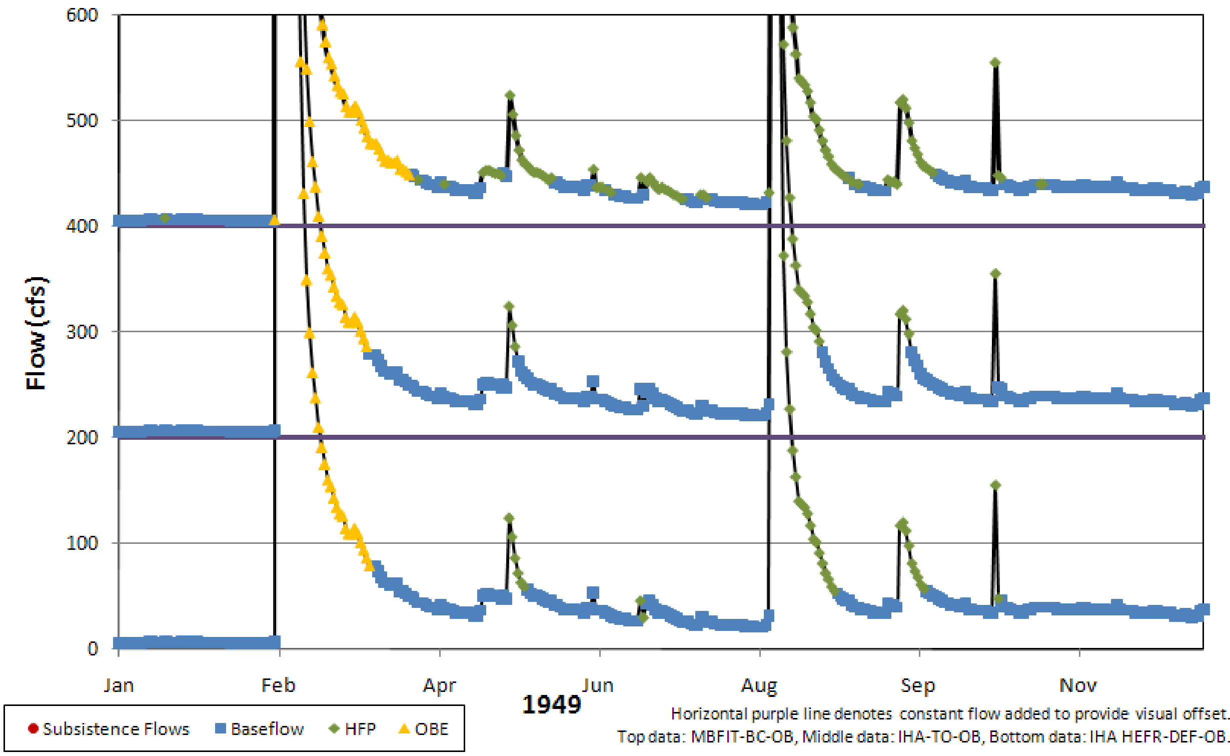

Figure 14. Comparison of Hydrographic Separation Methods for 1949

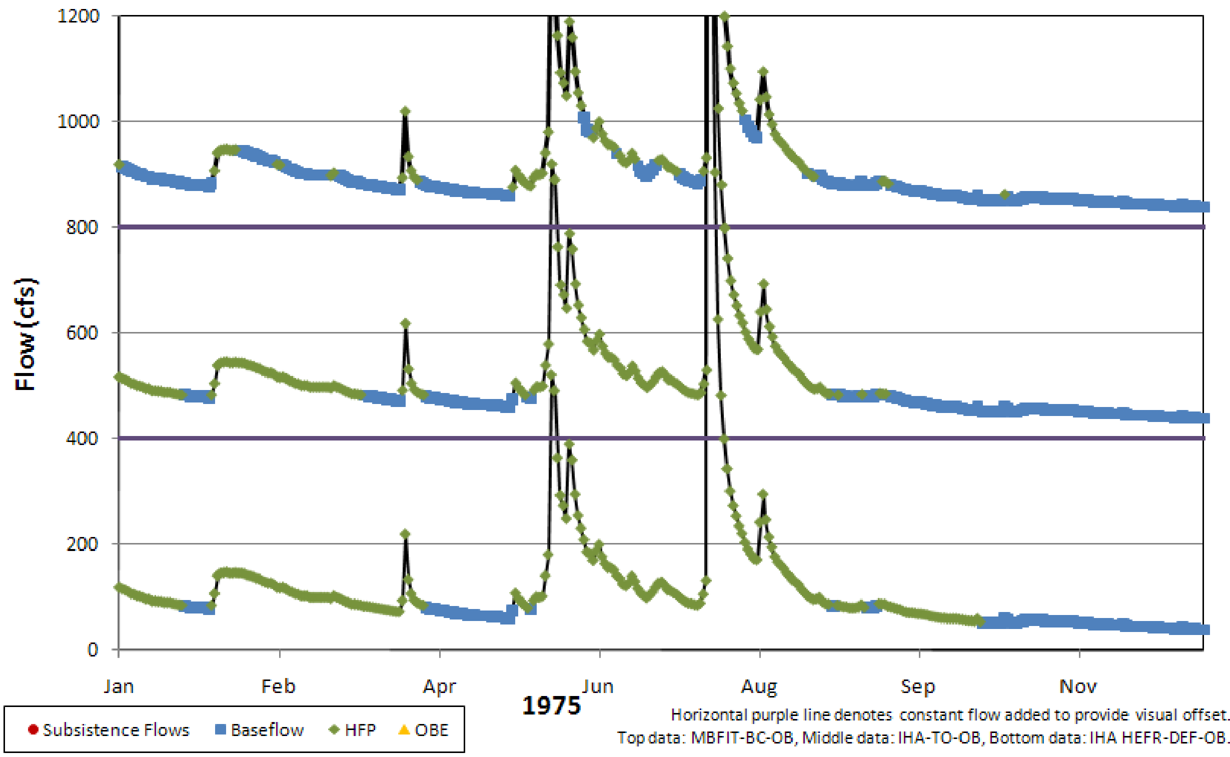

Figure 15. Comparison of Hydrographic Separation Methods for 1975

Again, the MBFIT panel in Figure 15 classified more discrete high flow pulse events. It also has some relatively high base flows (e.g., late January, late May, and late July). The first of these occurs during a relatively steady, but high, flow period, the second two are "high valleys" between runoff events. Partly because the upper and lower thresholds are set so wide in this example of the MBFIT algorithm, relatively high flows, if flanked by a storm event on either side, are classified as base flows.

Figures 16-18 show the HEFR output matrices for these simulations. Interestingly, the "high" base flows in the MBFIT-BC-OB simulation are substantially higher than either of the IHA simulations, most likely because of a fairly high percentage of "high valleys" such as shown in Figure 15. Note that larger high flow pulses (and overbank events) are identified as such by all three hydrographic separation methods, so the Qp at a given frequency is identical for these larger events. Smaller events are not necessarily identified by all methods. The MBFIT-BC-OB simulation identifies a one per season event for all seasons, whereas HEFR-DEF-OB identifies a one per season event for Spring, Summer, and Fall, and the IHA-TO-OB simulation identifies a one per season event only for the Summer.

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Overbank Flows	Qp: 18,500 cfs with Average Frequency 1 per 5 years Regressed Volume is 84,732 to 126,598 (105,665) Regressed Duration is 16 to 129 (45)											
High Flow Pulses	Qp: 2,460 cfs with Average Frequency 1 per year Regressed Volume is #N/A to 40,142 (19,347) Regressed Duration is 7 to 56 (20)											
	Qp: 435 cfs with Average Frequency 2 per year Regressed Volume is #N/A to 28,181 (7,381) Regressed Duration is 4 to 28 (10)											
				Qp: 28 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 14,702 (2,198) Regressed Duration is 1 to 8 (3)			Qp: 65 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 25,715 (2,822) Regressed Duration is 2 to 11 (4)			Qp: 51 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 33,125 (8,653) Regressed Duration is 1 to 13 (4)		
Base Flows (cfs)	37 (45.3%)	33 (45.1%)	35 (42.1%)	33 (42.4%)	41 (37.3%)	36 (43.4%)	38 (41.1%)	33 (43.5%)	32 (42.2%)	35 (42.4%)	40 (46.8%)	38 (48.5%)
	23 (61.4%)	22 (62.1%)	21 (60.4%)	20 (59.1%)	22 (56.3%)	19 (62.4%)	18 (60.3%)	18 (60.6%)	16 (59.0%)	18 (61.0%)	22 (63.3%)	23 (64.3%)
	11 (78.2%)	12 (79.6%)	12 (78.6%)	12 (77.9%)	13 (74.8%)	12 (78.5%)	11 (77.6%)	10 (76.8%)	8.2 (75.4%)	9 (76.8%)	11 (79.4%)	10 (79.4%)
Subsistence Flows (cfs)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)
	Winter			Spring			Summer			Fall		

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.

Figure 16. IHA HEFR-DEF-OB Simulation HEFR Outputs

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	Winter			Spring			Summer			Fall		
Overbank Flows	Qp: 18,500 cfs with Average Frequency 1 per 5 years Regressed Volume is 78,365 to 128,366 (103,365) Regressed Duration is 9 to 129 (34)											
High Flow Pulses	Qp: 2,460 cfs with Average Frequency 1 per year Regressed Volume is #N/A to 46,176 (21,319) Regressed Duration is 4 to 59 (16)											
	Qp: 435 cfs with Average Frequency 2 per year Regressed Volume is #N/A to 35,086 (10,218) Regressed Duration is 2 to 31 (8)											
							Qp: 85 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 31,226 (4,241) Regressed Duration is 1 to 9 (3)					
Base Flows (cfs)	37 (45.3%)	36 (43.7%)	36 (41.2%)	36 (40.6%)	44 (35.8%)	37 (42.2%)	39 (40.0%)	35 (41.0%)	34 (40.5%)	37 (40.9%)	43 (45.0%)	38 (48.5%)
	23 (61.4%)	23 (60.5%)	22 (58.1%)	20 (59.1%)	23 (54.8%)	20 (60.2%)	20 (58.1%)	19 (58.8%)	16 (59.0%)	19 (58.8%)	23 (62.2%)	23 (64.3%)
	12 (76.5%)	13 (76.5%)	13 (74.3%)	13 (74.9%)	14 (73.3%)	13 (76.9%)	11 (77.6%)	10 (76.8%)	8.4 (74.7%)	9.2 (75.5%)	12 (78.1%)	10 (79.4%)
Subsistence Flows (cfs)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.

Figure 17. IHA-TO-OB Simulation HEFR Outputs

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	Winter			Spring			Summer			Fall		
Overbank Flows	Qp: 18,500 cfs with Average Frequency 1 per 5 years Regressed Volume is 89,864 to 108,771 (99,318) Regressed Duration is 10 to 58 (24)											
High Flow Pulses	Qp: 2,460 cfs with Average Frequency 1 per year Regressed Volume is 5,628 to 24,390 (15,009) Regressed Duration is 5 to 30 (12)											
	Qp: 435 cfs with Average Frequency 2 per year Regressed Volume is #N/A to 12,732 (3,352) Regressed Duration is 3 to 17 (7)											
	Qp: 55 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 6,573 (569) Regressed Duration is 1 to 7 (3)			Qp: 107 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 7,420 (1,212) Regressed Duration is 2 to 11 (5)			Qp: 177 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 12,595 (1,590) Regressed Duration is 2 to 12 (5)			Qp: 155 cfs with Average Frequency 1 per season Regressed Volume is #N/A to 12,949 (2,331) Regressed Duration is 2 to 13 (5)		
Base Flows (cfs)	70 (31.4%)	78 (29.2%)	68 (28.7%)	63 (31.2%)	53 (30.2%)	41 (39.9%)	39 (40.0%)	34 (42.1%)	37 (37.5%)	48 (36.3%)	46 (43.5%)	54 (40.8%)
	29 (52.0%)	27 (52.4%)	27 (48.7%)	25 (51.3%)	27 (49.7%)	22 (57.8%)	20 (58.1%)	18 (60.6%)	20 (54.6%)	24 (53.9%)	24 (61.0%)	28 (58.6%)
	14 (73.7%)	14 (72.9%)	15 (69.9%)	14 (71.9%)	14 (73.3%)	14 (75.7%)	12 (76.1%)	9.8 (77.3%)	8.8 (72.9%)	12 (72.8%)	12 (78.1%)	11 (77.8%)
Subsistence Flows (cfs)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)	0 (100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.

Figure 18. MBFIT-BC-OB Simulation HEFR Outputs

In part because the MBFIT-BC-OB simulation identifies more discrete high flow pulse events, the regressed volumes and duration for the larger sized events (1 per 5 years, 1 per year, 2 per year) are smaller in the MBFIT-BC-OB simulation, as compared to either of the HEFR-DEF-OB and IHA-TO-OB simulations. However, the smaller sized events (1 per season) have a larger peak flow and smaller volumes in the MBFIT-BC-OB simulation, as compared to the HEFR-DEF-OB and IHA-TO-OB simulations.

The examples in this section are provided for illustrative purposes only. The IHA method has seven input parameters and MBFIT has eight, thus each method has significant flexibility and can generate different results, depending on the goals of the analysis.

5.5 EPISODIC EVENTS METHODS

HEFR has two methods for calculating high flow pulse and overbank flow recommendations. The user can select either method, but should recognize that these methods differ not just in their computations, but also somewhat in their conceptualization and interpretation.

5.5.1 Percentile Approach

The original conceptualization for high flow pulse recommendations involves the following general steps:

1. Using the population of high flow pulses identified by IHA (or other hydrographic separation algorithm), individually determine the 25th, 50th, and 75th percentiles (or alternate user-input percentiles) of event peak flow, event volume, and event duration for each season. Then identify high flow pulse events that meet or exceed the 75th percentile of all three characteristics (or a user-input combination of any/all of these three). This is the population of “high” qualifying high flow pulses. Then identify high flow pulse events that meet or exceed the 50th percentile of the selected characteristics (but not the 75th percentile); these are the “medium” high flow pulses. Those pulses that meet the 25th percentile of the selected characteristics (but not the 50th percentile) are the “low” high flow pulses. Those pulses that do not at least meet the 25th percentile of the selected characteristics receive no qualifying designation and are not included in subsequent calculations.
2. Assign a frequency recommendation for “high” high flow pulses as the 75th percentile of the historical frequency of occurrence of such pulses (rounded up if non-integer). Similarly, the “medium” and “low” frequency recommendations are equal to the 75th percentile of the historical frequency of occurrence of medium (and larger) and low (and larger) events, respectively.

Thus, the general approach in the original conceptualization of HEFR is to quantify percentiles of three flow characteristics, identify storm events that exceeded one or more of those characteristics, and set the recommended frequency based on the historical frequency. All calculations are performed on a seasonal basis. The user must select the desired percentiles as well as the desired suite of flow characteristics for classification (any combination of peak, volume, and/or duration).

Advantages:

- Consistency with other aspects of HEFR. The use of "high," "medium," and "low" and associated percentiles is consistent with the framework for base flows.
- Recognizes importance of three flow characteristics: peak, volume, and duration. While these characteristics are generally correlated in natural systems, in the future, as existing water rights are more fully exercised and if additional water rights are granted, these characteristics could become decoupled if only one is specified in an environmental flow requirement.

Disadvantages

- Low seasonal frequencies can be problematic. A combination of large events and short seasons generally leads to recommended frequencies of zero, one, or two (frequencies must be integers). Recommendations of zero are not meaningful and there is a big difference between a frequency recommendation of one and two when looking at total water volume.
- Lack of multi-year evaluation limits the size of recommended high flow pulses. The concept of limiting pulse sizes to only those storms that would occur at least once per season limits the size of high flow pulses that can be recommended.
- No meaningful way to establish hydrologic condition triggers that can be directly implemented in a way that ensures compliance with the recommended frequencies of occurrence – compliance can only be examined and achievement evaluated in hindsight after the occurrence, analysis, and pass-through of actual high flow pulses.

5.5.2 Frequency Approach

In contrast to the Percentile Approach that uses non-parametric statistics to identify qualifying episodic event characteristics, the Frequency Approach calculates the historical frequencies (or recurrence intervals) associated with the peak flows of episodic events. Both the Sabine-Neches and Trinity-San Jacinto BBESTs used the Frequency Approach in their HEFR simulations.

HEFR generates graphical and tabular displays of the historical occurrence frequency of peak flows. The analyst then chooses frequencies and associated peak flow values for desired event sizes; these become the recommendations in the HEFR output matrix. The analyst's choice is based upon the frequency information generated by HEFR combined with their knowledge of the system and understanding of the ecosystem roles of flows of different magnitudes and characteristics. Once the user selects a set of event sizes, the program uses a regression analysis to identify typical duration and volume characteristics associated with each peak flow. By providing regression prediction intervals, HEFR provides some quantification of the historical variability of duration and volume associated with the selected peak flows.

Frequency Calculations

The first step of this method is to establish the expected frequency of the observed peak flows from high flow pulses and overbank events.

A data series of peak flows is created that includes the peak of every high flow pulse event and overbank event identified by the hydrographic separation algorithm. This dataset of peak flows is then plotted in a series of annual and seasonal frequency curves (Figure 19) and tables using the Hazen plotting position (Stedinger et al, 1993). As two examples of the interpretation of this figure, a peak flow of 10,000 cfs is expected to have an average frequency of about 2.8 per year and 0.35 per Season 3 (Season 3 is from June to August). These frequency statistics are representative of the average behavior over the period of record and should be interpreted in the context of long-term behavior, not as a statement that exactly, e.g., 2.8 such events happen each and every year.

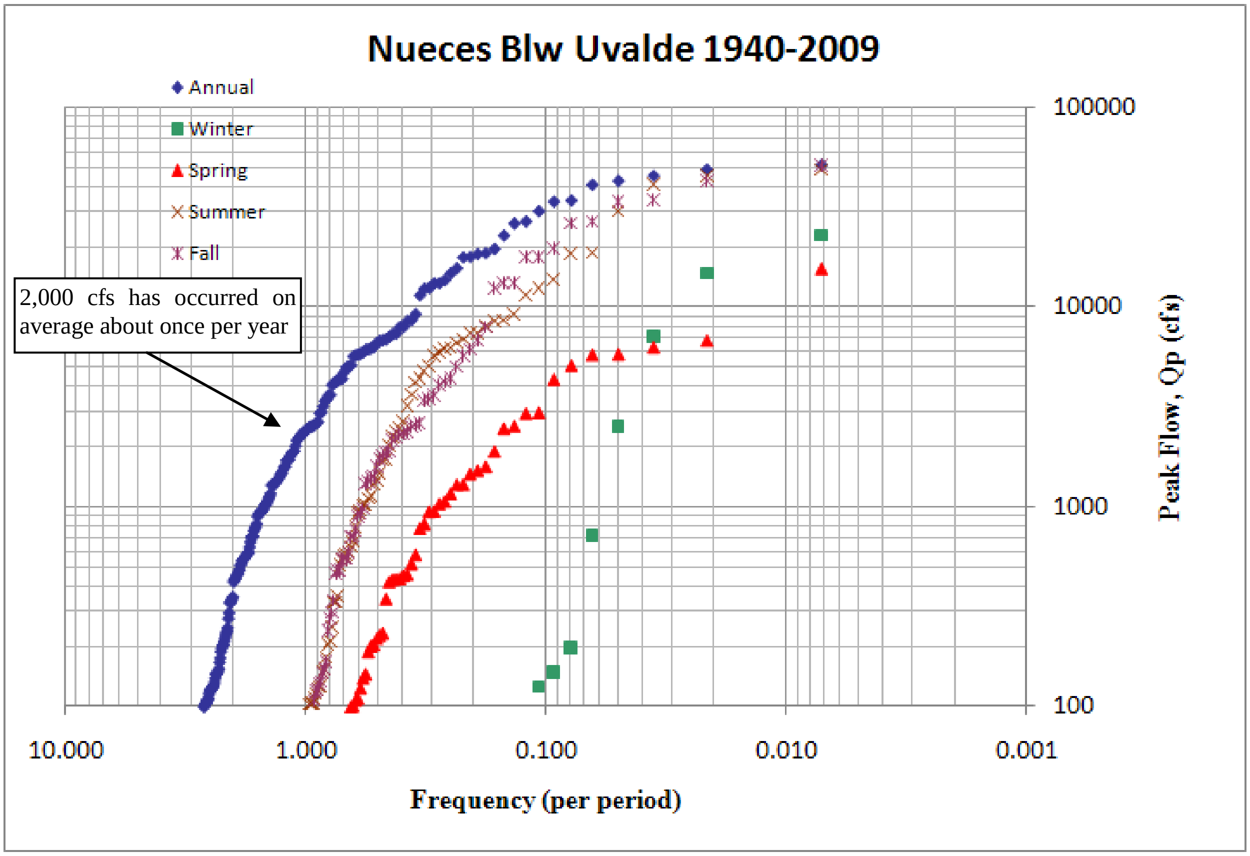

Figure 19. Frequency of Peaks Associated with High Flow Pulse and Overbank Events, Uvalde 1940-2009

Event Frequency Selections

The second step is for the analyst to use the frequency curve and tables, combined with knowledge of ecologically relevant high flow pulse and overbank event magnitudes, to select event magnitudes and associated frequencies for the flow recommendations. For example, if the analyst knows that some low-lying oxbows and backwater areas are inundated at a flow of 2,000 cfs (which is below bankfull) and that this should occur at (or near) the historical annual frequency, the analyst could select a frequency of 1 per year as a high flow pulse flow recommendation. The analyst may select several tiers of events, based on knowledge of the system.

Regressions of Peak Flow to Volume and Duration

The third step is to identify event volumes and durations associated with the selected peak flows (Qp).

This method has been developed using the correlation between historical peak flows and associated event volumes and durations. This method uses HEFR generated data series of peak flows, volumes, and durations developed for each high flow pulse and overbank event identified by the hydrographic separation algorithm. These data are binned by season, and two regression calculations are performed in each season, one of event duration versus peak flow and one of event volume versus peak flow.

Regression options include a natural log (ln/ln) regression and a quadratic regression. The analyst must select the regression form for the final flow matrices before the calculations are complete. However, in the raw calculation tables and figures, results from both regression options are provided in each run. The analyst should carefully consider the regression forms, the fit of the regressions (particularly in the vicinity of desired Qp values), the provided residuals diagnostic plots, and the utility of the best-fit and prediction intervals on a case by case basis. If, upon review of these regression results, the analyst decides that a different regression form is desired for the final flow matrices, HEFR must be rerun from the beginning with that selection.

Because a regression attempts to provide a best fit to all of the data, the fit at low values of Qp may be poor. In some cases when using the quadratic regression equation, the lower prediction interval and/or the best-fit line may cross the x axis and predict negative high flow pulse volumes and/or durations. In such cases, the negative value is replaced with #N/A to signify to the user that this regression should be inspected carefully and alternative regression forms and/or methods be employed.

The generated regression output (Figure 20) provides estimated prediction intervals[30] which illustrate upper and lower bounds on the predicted volumes and/or durations for the selected peak flows. The green lines are the lower and upper prediction intervals. The red line is the regression best-fit. The red "*" is the recommendation shown in the HEFR output matrix.

[30] The prediction interval is the interval that is expected to contain a single future value of the dependent variable (i.e., volume in Figure 20) at the user specified degree of confidence (Berthouex and Brown, 1994).

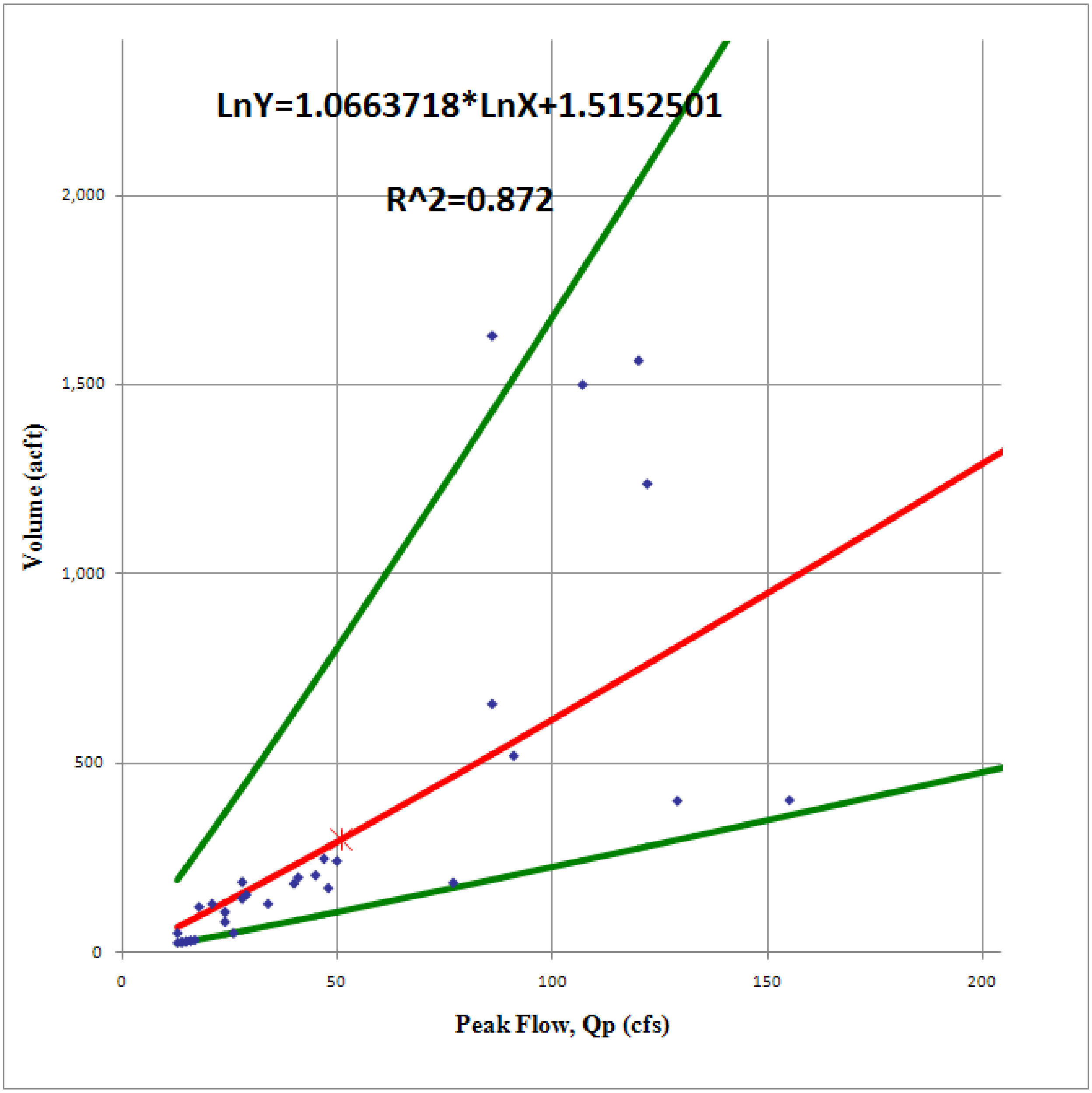

Figure 20. Volume vs. Peak Flow

While the regressed volume and duration associated with each recommended peak flow is provided in the final flow matrices, it is important to remember that the listed event frequency (e.g., average frequency one per season) is associated with the peak flow only. Events that equal or exceed all three characteristics of peak flow, volume, and duration will have occurred less frequently in the historical record than those that equaled or exceeded the peak flow only.

HEFR also calculates the historical occurrence frequency of the selected episodic events, not just the average frequency. Table 1 shows a condensed version of a HEFR output table that provides such historical frequencies. For example, the Tier 2 annual event (435 cfs, see Figure 16) never occurred in about 46% of the years in the period of record. One such event occurred in about

26% of years, two occurred in 16% of years, 3 occurred in 11% of years, and 5 occurred in 1.4% of the 70 year period of record (i.e., one year).

Table 1. Historical Frequency of Overbank Events and High Flow Pulses

Number of Events per Period	Overbank	Tier1	Tier2	Tier 3		
	Annual	Annual	Annual	Spring	Summer	Fall
0	81.4%	45.7%	24.3%	42.9%	47.1%	47.1%
1	18.6%	25.7%	17.1%	31.4%	24.3%	17.1%
2	0.0%	15.7%	25.7%	14.3%	14.3%	25.7%
3	0.0%	11.4%	15.7%	7.1%	11.4%	8.6%
4	0.0%	0.0%	5.7%	2.9%	1.4%	1.4%
5	0.0%	1.4%	10.0%	1.4%	1.4%	0.0%
6	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%
Check 100%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 1 is based on the historical frequency of events that meet the recommended peak flows. HEFR outputs a similar table of events that meet all three characteristics of peak flow, volume, and duration. These tables should be consulted when the analyst crafts interpretation language surrounding episodic event recommendations. It is important that the intended recommendation frequency of such events be carefully described.

Advantages:

- Multi-year recommendation window allows for larger events and more closely matches inter-annual variability.
- Regressions provide an explicit estimate of variability in volumes and durations associated with peak flows.
- Flexibility in frequency selection allows user to apply knowledge to pick events of desired sizes.
- Can accommodate the entire spectrum of event magnitudes.
- Frequency of occurrence within each season can be identified using seasonal datasets.
- The user is allowed to select the seasonal assignments, number of tiers, and frequency associated with each high flow pulse and overbank event level.

Disadvantages:

- Regression outputs need to be carefully examined to ensure that the best-fit and prediction intervals are reasonable in the vicinity of desired peak flow values.
- No meaningful way to establish hydrologic condition triggers that can be directly implemented in a way that ensures compliance with the recommended frequencies of occurrence – compliance can only be examined and achievement evaluated in hindsight after the occurrence, analysis, and pass-through of actual high flow pulses.

This calculation approach requires the user to make appropriate judgments based upon basin-specific information to select the seasonal assignments, number of tiers, and frequency associated with each high flow pulse and overbank event level. This could be seen as a disadvantage (because it requires more effort on the part of the user) or an advantage (because it allows more site specific information to be applied).

5.6 NON-ZERO FLOWS OPTION

HEFR has an option to calculate subsistence flows and base flows using non-zero flows only. This option may be helpful for intermittent and ephemeral streams. If this option is turned on, zero flows are omitted from calculations of subsistence flows, base flows, and the historical occurrence frequencies of both. It is expected that the historical frequency of zero flows will still be recognized as part of the flow regime, just not as part of the usual four flow components. There is no clear guidance regarding when or how the option to consider only non-zero flows is to be considered when evaluating environmental flow requirements for subsistence and base flows. At best, it provides another set of flow values that could be helpful when developing environmental flow recommendations.

Table 2 shows how the calculations differ when the option for non-zero flows is turned on or off.

Table 2. Impact of Non-Zero Flows Option on Calculations

	Subsistence Flow Calculations		Base Flow Calculations	
	Non-Zero Flows Option			
Frequency of Zero Flows	OFF	ON	OFF	ON
0%	no difference		no difference	
0 - 10% of initially identified base flows	Median of all subsistence flows, including zeros	Median of non-zero subsistence flows, therefore a higher number	No difference in flows. Reported historical frequency is different because "OFF" option is based on all flows and "ON" option is based on days with flow	
>10% of initially identified base flows	Result is zero because all subsistence flow days are zero and the median of all zeros is zero.	Result is #N/A because all subsistence flow days are zero and therefore the calculation is not possible	No difference in flows. Reported historical frequency is different because "OFF" option is based on all flows and "ON" option is based on days with flow	

5.7 SUMMARY

HEFR is a calculation methodology for populating a flow regime matrix consistent with the TIFP environmental flow regime framework. The core of HEFR is hydrograph separation and summary statistics of the resulting flow regime components (calculated in Excel). Reasonable changes to specific parameter and statistical decisions, established in a collaborative manner, are an integral part of the HEFR approach. Parameter selections presented here are for example purposes only.

HEFR outputs are internally consistent in the sense that higher flows are naturally associated with lower frequencies. In this way, HEFR attempts to mimic (with a limited number of flow regime components) key elements of the period of record used. In short, the goal of HEFR is to help identify key elements of the historical hydrograph that, when evaluated with other data and relationships pertaining to biology, water quality, geomorphology and other disciplines, are associated with important ecological benefits. This information, when applied to the operation of proposed water development projects, can help guide ecologically sound water management decisions.

HEFR-generated flow regime matrices with multiple flow regime components and levels are a rather complex representation of environmental flow requirements at a particular location on a river. Although these are the types of flow regimes that may be most applicable for most locations on major streams and rivers, under some circumstances, such as recommendations for a small stream, a less complex flow matrix could be appropriate. In addition, for permits such as those involving only small run-of-river diversions, permit conditions may only need to include a subset of the flow components in this matrix.

As described herein, application of the HEFR program requires specification of a number of parameters to define different flow levels and conditions that are used to describe a resulting environmental flow regime at a particular location on a stream or river. Determining optimal values of these parameters is not a straightforward process and depends on: (1) basin and site specific characteristics of hydrology, biology, geomorphology, and other related disciplines and (2) project specific objectives based on environmental, stakeholder, legal, management, and other concerns. Still, it is important to establish initial values of these parameters that can provide at least a starting point for the application of the HEFR methodology in the absence of all of the information that ultimately might be needed and considered in arriving at a final environmental flow recommendation. Appendix A presents "default" values for the most important input parameters needed to initially apply HEFR. Again, it is anticipated that these parameter values very likely could change as the determination of final environmental flow recommendations at a particular location proceeds through the overall process.

SECTION 6
CONCLUSIONS

SB 3 directed the use of an environmental flow regime for developing flow standards. Further, it defined an environmental flow regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats.

The nature of streamflow magnitudes and variations plays an important role in determining the characteristics and viability of a riverine ecosystem. In water bodies having a sound ecological environment, historical hydrology has likely been a dominant factor that has influenced the state of the system. Where data are insufficient to establish relationships between streamflow and biological response, the historical streamflow data themselves can provide a meaningful basis for establishing, as a first approximation, environmental flow recommendations that are considered to be protective of current conditions. It is also necessary that these initial recommendations be subject to refinement and adjustment based on available biological data and other information to better reflect actual ecosystem needs.

This document provides an overview of how hydrologic data can be used in the identification of instream flow recommendations as part of SB 3 efforts. As such, it describes one piece of a collaborative process envisioned by SB 3 for the identification of instream flow regimes to maintain a sound ecological environment. It does not address assessment techniques for environmental freshwater inflow determinations for bays and estuaries. In addition, information from other disciplines such as biology, geomorphology (physical processes), and water quality will be necessary to guide hydrologic analyses, address decision points, and refine/replace instream flow recommendations that are based on hydrologic data alone. It is important to remember that the hydrologic methods discussed herein have not been validated against biological, geomorphological, and/or water quality data and are not based on defined flow alteration - ecological response relationships. However, information from other disciplines can and should be used to corroborate or refine hydrology-based instream flow recommendations. The hydrologic analyses discussed herein constitute simply the first, and perhaps the easiest, step in the process of developing instream flow recommendations.

Specifically with regard to the establishment of instream flow recommendations for rivers and streams, the SAC offers the following observations:

- Pursuant to the requirements of SB 3, instream flow recommendations developed by the BBESTs must represent a flow regime that includes a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats.
- In order both to implement the SB 3 requirements and to effectively utilize the results from the TIFP studies through the adaptive management process, it is recommended that

the initial SB 3 instream flow recommendations be consistent with the environmental flow regime framework that is to be applied in the TIFP studies, including, as appropriate, the following four flow regime components:

  - Subsistence flows
  - Base flows
  - High flow pulses
  - Overbank flows

- From the standpoint of developing and implementing environmental flow requirements associated with a water right on a stream or river, it is important to recognize that fully satisfying the need for the higher flow components often may be dictated more by the natural stream itself than the water right activity, e.g., the diversions authorized by a water right or group of water rights may be of such magnitude that they simply cannot significantly impact high pulse flows or flows that cause overbanking.

- Environmental flow recommendations structured in accordance with a flow regime framework can incorporate, as appropriate, different levels of flow requirements to reflect monthly or seasonal variations and different hydrologic conditions (dry-average-wet or low-medium-high).

- Depending on stream conditions, different components of the environmental flow regime matrix can be used to structure appropriate environmental flow requirements, and not all elements of environmental flow components may be needed to develop an adequate and protective environmental flow standard.

- In the absence of known flow alteration – ecological response relationships for specific locations or stream reaches within a basin, the application of hydrology-based instream flow methods to statistically define an environmental flow regime offers a useful approach for initially establishing instream flow recommendations consistent with the requirements of SB 3.

- For the purposes of SB 3, establishing environmental flow recommendations should ideally be based on a relationship between flow and ecological response. However, it is likely that data will be lacking to identify this relationship in many instances. In the absence of an appropriate flow alteration – ecological response relationship, then the only remaining tool is likely to be a hydrology-based instream flow method. Using a hydrology-based method in lieu of a flow-ecological response method assumes that maintaining the occurrence and frequency of key flow characteristics derived from historical records provides a flow that is likely adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats. However, this assumption presumes that the historical flows did indeed support a sound ecological environment. In fact, for those cases where a sound ecological environment does not exist, the hydrology-based results might not necessarily provide what is needed by the environment, or where a sound ecological environment has been determined to exist, the hydrology-based results very well may be in excess of what's required.

- It is recognized that with more rigorous scientific data and information such as that being developed through the TIFP studies, the environmental flow recommendations derived using hydrology-based instream flow methods are subject to revision and updating through the adaptive management process provided for in SB 3.

- The period of record selected for application of hydrology-based instream flow methods typically represents one of three conditions: (1) natural, pre-human impacts, (2) post-human impacts or regulated conditions, or (3) all historical development as reflected in the entire available flow data base, and the selection of the most appropriate period of record should consider such factors as the length of available daily flow records, historical changes in the basin that have influenced hydrologic conditions, the characteristics of historical and existing ecosystems, and the likely flow conditions under which the existing ecosystem evolved and has become adapted.
- Application of hydrology-based instream flow methods for establishing environmental flow recommendations requires numerous decision points regarding parameter values and assumptions and necessarily involves considerable expertise, experience, and professional judgment to achieve meaningful results.
- The Hydrology-based Environmental Flow Regime (HEFR) methodology, developed by the TPWD with input from other agencies and organizations, provides a relatively flexible statistical approach for developing a flow regime matrix that is consistent with the TIFP multi-tiered flow framework for describing key and essential instream flow requirements.
- With application of the necessary expertise, experience, and professional judgment, the HEFR method can provide useful results that potentially can be used to initially structure environmental flow recommendations for rivers and streams that are consistent with the requirements of SB 3.
- Where data are available, it is essential that information on biology, water quality and sediment transport be used to adjust or refine the hydrology-based flow regime recommendations to better reflect actual environmental flow needs and to provide more appropriate environmental flow requirements.

SECTION 7
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APPENDIX A
DEFAULT VALUES FOR HEFR

This appendix contains suggested default values for developing a preliminary HEFR analysis. These values are suggested simply as a place to start. Optimum final values will depend on: (1) basin and site specific characteristics of hydrology, biology, geomorphology, and other related disciplines and (2) project specific objectives based on environmental, stakeholder, legal, management, and other concerns.

Characteristic	**Default Value**
IHA EFC – HFP Upper Percentile Threshold	75%
IHA EFC – HFP Lower Percentile Threshold	25%
IHA EFC – HFP Rate of Increase Trigger	50% per day
IHA EFC – HFP Rate of Decrease Trigger	5% per day
IHA EFC – Small Flood Threshold Recurrence Interval	1.5 years
IHA EFC – Large Flood Threshold Recurrence Interval	99 years (or uncheck box in IHA7.1)
IHA EFC - Extreme Low Flow Threshold	10%
Excel – Multipeaks_Multiplier for HFPs	1.5
Excel – Multipeaks_Multiplier for Overbank Flows	1.5
Excel – Monthly Seasonal Assignments	Winter – Dec, Jan, Feb Spring – Mar, Apr, May Summer – Jun, Jul, Aug Fall – Sep, Oct, Nov
Excel – Non-Zero Flows Option	Off
Excel – Subsistence Flow Percentile	0.5 (for 50th percentile)
Excel – Base Flow Percentile Assignments	Low: 25th percentile of base flows Medium: 50th percentile of base flows High: 75th percentile of base flows
Excel – HFP Percentile Approach: Assignments for Volume, Peak Flow, and Duration	Low: 25th percentile of all three Medium: 50th percentile of all three High: 75th percentile of all three
Excel – HFP Percentile Approach: HFP Frequency Recommendation	75th percentile of historical frequencies
Excel – Percentile Approach: Overbank Flows Percentile Assignment for Volume, Peak Flow, and Duration.	50th percentile
Excel – Percentile Approach: Overbank Flow Frequency Recommendation	Average return interval of recommended event
Excel – Frequency Approach: Confidence Interval	68.3
Excel – Frequency Approach: Regression	LN/LN

Forms	
Excel – Frequency Approach: HFP and Overbank Tiers	Range from large to small